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Factors influencing colonization and establishment of plant species on cranberry bogs.

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FACTORS INFLUENCING COLONIZATION AND ESTABLISHMENT OF PLANT SPECIES ON CRANBERRY BOGS

A Dissertation Presented

by

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DEDICATION

I would like to dedicate this research and dissertation to my parents, Morton and Frances Sandler.

You have always believed in the pursuit of education, and have supported my many endeavors to attain it. Even though I started this part of my education somewhat late in life, you were totally behind me. Your confidence in my abilities has been unwavering, and certainly your love has never faltered. I will always remember that you both called the night before my defense to wish me luck, and told me of your pride when we talked the next day as I told you of my success.

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Now I hope you will.

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ABSTRACT

FACTORS INFLUENCING COLONIZATION AND ESTABLISHMENT OF PLANT SPECIES ON CRANBERRY BOGS

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The objective of this study was to obtain and interpret field data related to the establishment of cranberry (*Vaccinium macrocarpon* Ait.) plantings, as well as examine the impact of conventional weed management practices on yield components and weed control. Integrated weed management, recognized by weed scientists as a desired goal for research and extension, is an important part of current cranberry production. This research was designed to permit the incorporation of the collected data into practical grower recommendations, as well as to expand our general knowledge about invasion ecology and plant species composition in new and established commercial plantings.

Data from four years of repeat annual applications of 0, 1.8, and 4.5 kg ai•ha^{-1} dichlobenil in low-weed and high-weed density areas indicated minimal negative impact on cranberry vines. Herbicide application did not adversely affect upright productivity, biomass,

fruit set, or other yield parameters; in addition, no improvements for these parameters were noted. No consistent treatment effect on cranberry root length was seen. The presence of weeds, rather than herbicide application, was the important determinant of yield. Vines in low-weed areas produced more marketable fruit and had higher percentage fruit set than vines growing in high-weed density areas. Results suggest that repeat annual applications of dichlobenil to commercial cranberry beds may be considered as part of a viable integrated weed management program with no adverse effect on crop growth or yield.

One specific goal of this research was to identify the most beneficial combination of nitrogen rate (0, 28, 56, 112 $kg \cdot ha^{-1}$), vine planting density (0, 1.8, 3.6, and 5.4 $t \cdot ha^{-1}$), and weed management option (preemergence, postemergence, inoculation, and untreated) that would promote quick and economical vine establishment of the cultivar, Stevens, while providing adequate and cost-effective weed control. After two years, several treatment combinations seemed promising for commercial implementation. However, the most cost-effective production scheme for establishing a new planting was to plant vines at a low density, use moderate rates of nitrogen, and apply a yearly application of napropamide for weed control. This combination produced substantial vine coverage and reduced weed biomass by 85% compared to untreated plots.

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CHAPTER 1

INTRODUCTION

Background and Overview

Cranberry (*Vaccinium macrocarpon* Ait.) is a low-growing, trailing, broadleaf, nondeciduous perennial vine (Eck, 1990). Leaves are narrowly elliptical, 2-3 mm wide by 5-8 mm in length. Cranberry vines consist of lateral, woody runners that may grow in excess of 2 m in length and tend to form a dense mat on the bog floor. Intermittent vertical stems, called uprights, originate from leaf axils on these runners. Uprights, which are between 5 and 20 cm tall, may be either vegetative or fruit-bearing. In any particular year, a substantial portion of uprights in a population will have a terminal bud; the remaining uprights have no bud. From this group of terminal buds, some will be vegetative; the rest will contain floral initials. On typical fruit-bearing uprights, three to five flowers are borne on their own pedicel in alternate arrangement. The lowermost fruit are the first to mature. The most common cultivars planted in Massachusetts are Early Black, Howes, and Stevens. Mature fruit of cultivars Early Black and Howes weigh approximately 0.8-1 g per berry; mature Stevens fruit weigh approximately 1.5-2 g per berry.

To produce economically competitive yields, commercial growers strive to achieve a density of cranberry vines in the range of 600 uprights per 900-cm^2 ground area for 'Early Black' and 400 uprights per 900 cm^2 ground area for 'Howes' and 'Stevens' (DeMoranville, 2001). Of these, 200 or more should be fruit-bearing uprights. If each of these uprights produces one to two viable fruit, the vines will yield approximately 33.6 $t \cdot ha^{-1}$ (~300 barrels per acre) of cranberries.

Many factors may interact and contribute to lower realized cranberry yields. Weather is a significant determinant in fruit production (DeMoranville et al., 1997). Competition for light may be a factor leading to reduction of fruit quality (Sapers et al., 1986). In addition, the availability

of water and nutrients will also affect overall yield. Insect, weed, and disease pressures limit cranberry productivity to different extents in any given year (Mahr and Moffitt, 1994). Growers may need to use pesticides and various cultural practices (DeMoranville et al., 1996) to manage pest populations that threaten their crops. Conventional cultural practices are nonchemical horticultural techniques that include such activities as periodic flooding and the application of thin layers of sand (<5 cm) on the bog surface. Growers also apply fertilizers and irrigate on a regular basis to provide supplemental nutrients and water. Normal agricultural activities introduce energy and materials into managed farm systems that may impact the environment as a whole. For example, energy inputs are required to maintain a monoculture of cranberry; sand, fertilizer, and pesticides are typical material inputs.

Cranberries grow and reproduce in a biological network that is much larger than the field in which the vines are initially planted. Scientists and growers, to various extents, appreciate the interrelationships that exist between the traditional farm area with its associated activities and the surrounding environment. With increasing environmental and conservation pressures from society, successful farming operations must embrace practices that minimally impact the ecosystem as a whole. Integrated crop and pest management programs offer a good framework on which to base successful farming practices.

Integrated pest management (IPM) can be defined as an ecologically based pest management program that combines biological, chemical and cultural strategies to minimize the economic loss caused by a pest and adverse environmental impacts (Metcalf and Luckman, 1975; Bajawa and Kogan, 1996). IPM has been the structural framework by which cranberry growers have attempted to manage various pests for more than two decades (Sandler, 1997b). The implementation of weed IPM has been adopted by the industry as strategies have been made available through research and extension. Modern cranberry production is intensive and creates a specialized complex of interacting biotic and abiotic factors that comprise the agricultural ecosystem.

To be good stewards of these agroecosystems, growers and researchers alike must gain a better understanding of the organisms and relationships in the system. The goal of the proposed research is to increase the knowledge base relating to the complex of terrestrial plant organisms found within agricultural and natural ecosystems containing the genus, *Vaccinium*.

Farmers have identified an informal class of plants, weeds, which are intrusive to their agricultural activities. Though perhaps under-appreciated by modern farmers, these plants play an important role in the larger web of organismal interactions and energy exchange within the agroecosystem. Weeds, exemplified by their ability to occupy available niches within the agroecosystem, are a successful group of plant species. Recurring agricultural practices place selective pressures on these species (Dekker, 1997). A consequence of these annual activities is that the adaptive species become the most challenging weed management problems.

Weeds are not easy to define (Radosevich et al., 1997; Zimdahl, 1999). Weeds have been called plants 'out of place' or plants growing where they are not wanted. From an ecological perspective, a weed has been defined as "a plant that originated in a natural environment and, in response to imposed or natural environments, evolved, and continues to do so, as an interfering associate with our crop and our activities" (Aldrich, 1984). It is a plant that competes with another plant that is, by definition, our primary point of interest. All plants need water, light, nutrients, and space to successfully reproduce. Even though many commercial cranberry growers would prefer to have a monoculture of cranberry vines, the plant community of commercial cranberry fields typically consists of a wide range of plant species. Over 80 species of plants outside of the *Vaccinium* genus have been described (Cross, 1952; Demoranville, 1984; Demoranville, 1986; Eck, 1990) on commercial cranberry bogs. These plants vary in their ability to colonize the field and impact yield of cranberry vines (Else et al., 1995).

Weeds often limit the commercial production of many crops (Holm et al., 1997; Zimdahl, 1999) including cranberry (Mahr and Moffitt, 1994; Patten and Wang, 1994). Weed interference in lowbush blueberry (*Vaccinium angustifolium* Ait.) has been well documented (Eck and Childers,

1967; Yarborough and Bhowmik, 1993). Weeds have been cited as one of the major factors that limit productivity for cranberry growers in Massachusetts (CCCGA survey, 1993). Patten and Wang (1994) showed that weed competition impacted cranberry yield more severely than fruit size or color. Weeds may interfere with harvest operations as well as irrigation and pesticide applications (Sandler, unpublished).

Preemergence herbicides suppress, but do not eradicate, many weed species that grow in cranberry bogs. In addition, the prostrate growth habit of cranberries limits postemergence control options for commercial growers. Due to the acidic environment typical of cranberry agroecosystems, many weeds survive but do not prosper. Since many weeds occupy the same canopy space as cranberries (less than 30 cm in height), postemergence applications of broad-spectrum herbicides cannot be used without risking severe injury to the crop plant. The herbaceous character of the ubiquitous grass, sedge, and rush species, as well as several broad-leaved weeds, makes herbicide wiping (by hand or stick device) a difficult task.

Weeds may impact the establishment, growth, and/or fecundity of cranberry vines. Previous research (Hicks et al., 1968) showed that the density of established cranberry vines growing in weedy areas was greatly reduced compared to nonweedy areas. In addition, they found a lower percentage of flowering uprights and fewer flowers per upright in the weedy areas. If planted at a high density, can cranberry vines colonize a bare surface faster than weeds and minimize the negative impact of the weeds? No work has been published that examined the interaction of weed biomass production and vine density in newly established cranberry beds.

Weed management, through the broadening of our knowledge base of weed biology and ecology, has gained momentum during the past few years. The Weed Science Society of America sponsored a symposium, entitled "Importance of weed biology to weed management" at their annual meeting in 1996 (Oliver, 1997). The Weed Science Society of Japan started publication of a new journal called "Weed Biology and Management" in 2001 (Kobayashi, 2001). Current researchers acknowledge the complexities of the crop-weed interplay and proffer

thoughts on future research opportunities and potential complications (Martinez-Ghersa et al., 2000). Certainly, the sustainability of agriculture depends on developing and understanding the dynamics between the weed and the crop.

Research Objectives

The research herein was designed to contribute to the scientific body of knowledge of weed science, with particular emphasis on the commercially cultivated wetland plant, *Vaccinium macrocarpon*. Several questions provided the genesis of this research. Do conventional horticultural practices influence the species composition of plants in the cranberry agroecosystem? Do typical weed management practices favor weed invasion in established cranberry beds by weakening the vines? What are the weed-crop relationships involved in establishing a new cranberry planting? Can weed management strategies be developed that favor the cranberry in the "weed-crop" dynamic? Can fertilizer programs be altered to favor the establishment of cranberry vines planted into bare ground?

To this end, the specific research projects pursued were to:

- Evaluate the impact of repeated applications of dichlobenil (pre-emergence herbicide) on plant community structure and cranberry productivity;
- Evaluate the influence of various management strategies (e.g. herbicide use, hand-weeding) on plant community structure and vine biomass production;
- Document the composition of the plant community that developed under various nitrogen fertilizer programs and cranberry vine planting densities; and
- Determine the cost-efficiency of the various treatment combinations, and develop grower recommendations for planting new cranberry beds.

CHAPTER 2

EFFECT OF REPEAT ANNUAL APPLICATIONS OF DICHLOBENIL ON WEED POPULATIONS AND YIELD COMPONENTS OF CRANBERRY

Introduction

Application of synthetic herbicides in perennial and annual crops has been a common practice for decades (Zimdahl, 1999). As a result, many studies on repeat annual applications of herbicides have been reported in the literature. Data have been published on several perennial crops such as apples (*Malus x sylvestris* (L.) Mill. var *domestica* Borkh.) and lowbush blueberries (*Vaccinium angustifolium* Ait.) as well as annual crops such as cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.). Many reports present data supporting the premise that long-term use of herbicide in agricultural systems is beneficial to the crop plant, both in perennial (Mellenthin et al., 1966; Schubert, 1972; Skroch et al., 1975; Heeney et al., 1981b; Yarborough and Bhowmik, 1989; Lapointe and Rochefort, 2001) and annual (Triplett and Lytle, 1972; Hayes et al., 1981; Keeling and Abernathy, 1989) crop systems.

Even though the crop plant may not be negatively affected, the effect on weed populations can be variable with repeat annual applications of the same herbicide. Weed population shifts occurred when terbacil (5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4-(1H,3H)-pyrimidinedione) and dichlobenil (2,6-dichlorobenzonitrile) were applied annually for a 5-yr period to an apple orchard (Skroch et al., 1975). Dewberry (*Rubus* spp.) and Virginia clematis (*Clematis virginiana* L.) populations increased with a high rate of terbacil (active ingredient (a.i.) applied at 4.5 kg•ha^{-1}), and dewberry and goldenrod (*Solidago* spp.) populations increased with high (9 kg a.i. ha^{-1}) and low (4.5 kg a.i. ha^{-1}) rates of dichlobenil, respectively. Six annual applications of dalapon (2,2-dichloropropionic acid) + dinoseb (2-(sec-butyl)-4,6-dinitrophenol),

at five times the recommended rate (applied at 47.6 +84.0 kg a.i. ha^{-1}, respectively), increased the percentage of broad-leaved weeds, especially mouseear chickweed (*Cerastium vulgatum* L.) and red sorrel (*Rumex acetosella* L.) (Schubert, 1972). Repeated use of simazine (6-chloro-N,N′-diethyl-1,3,5-triazine-2,4-diamine) selected for a genotype of common groundsel (*Senecio vulgaris* L.) that was less susceptible to the herbicide (Holliday and Putwain, 1980).

Conversely, weed surveys in lowbush blueberry after 8 yr of hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) applications indicated that some species apparently disappeared and that all species showed a reduction in abundance. Shifts towards herbicide-resistant species were not seen in this study (Lapointe and Rochefort, 2001). In another recent study, repeated use of a combined high rate (4.4 kg a.i. ha^{-1}) of diuron (N′-(3,4-dichlorophenyl)-N,N-dimethylurea) and a low rate of terbacil (2.2 kg a.i. ha^{-1}) provided excellent weed control in an experimental site for 15 years (Tworkoski et al., 2000). In a 6-yr study, acceptable weed control was seen in a mature apple orchard that received repeat annual applications of simazine (4.4 kg a.i. ha^{-1}), diuron (4.4 kg a.i. ha^{-1}), terbacil (4.4 kg a.i. ha^{-1}), and dichlobenil (8.8 kg a.i. ha^{-1}) compared to an untreated check (Heeney et al., 1981b).

Dichlobenil, a preemergence granular herbicide registered in 1964 (Cox, 1997), has been used in the cranberry industry for decades to control annual and perennial grasses, sedges, and broad-leaved weeds (Dana et al., 1965; Demoranville, 1984). Dichlobenil residue and its persistence in the soil have been documented in various agricultural (Miller et al., 1966; Heeney et al., 1981b) and other ecosystems (Cox, 1997). Dichlobenil has been shown to persist in the top 15 cm of soil in cranberry beds (Miller et al., 1966) and apple orchards (Skroch et al., 1975). The cranberry study indicated that the total quantity of dichlobenil residue was higher for samples collected from cranberry beds that received two annual applications of the herbicide compared to soil samples that had received a single application (Miller et al., 1966). The authors suggested that dichlobenil could persist over time and its effect on vine health should be considered in future cranberry research. In an effort to mitigate the peresistence of herbicide residues through

repeated use of the same herbicide, alternative herbicide programs have been evaluated. Residue levels in apple orchard soil were lowered when weed populations were managed with an herbicide rotation (Heeney et al., 1981a).

As cited above, much of the literature relating to annual repeat applications reports on the herbicides simazine, terbacil, and diuron. Of the few reports that exist on the effect of long-term use of dichlobenil, results are mixed. Apple trees in North Carolina treated with five annual applications of 4.5 and 9.0 kg a.i. ha^{-1} dichlobenil showed no significant tree growth increases with either rate, but yield increases were noted at the high rate (Skroch et al., 1975). Apple trees, grown in eastern Ontario, Canada, treated with six annual applications of 8.8 kg a.i. ha^{-1} dichlobenil had improved tree health (e.g., greater annual increase in mean trunk and limb circumference), but no yield increase (Heeney et al., 1981b). One recent study examined the effects of excessive annual applications of these four herbicides on young apple trees. In this case, six annual applications of various rates (4, 8, and 16 kg a.i. ha^{-1}) of dichlobenil did not detrimentally affect tree vigor or yield (Hogue and Neilsen, 1988).

The mode of action of dichlobenil is not well understood (Vencill, 2002). However, it is thought to inhibit actively dividing meristimatic tissue in the root and shoot by hindering cell wall formation through disruption of cellulose synthesis (Cox, 1997). The impact of the herbicide on root initiation is important for cranberry horticulture, and dichlobenil should not be applied to newly planted vines (Sandler, 2003). Similar to the study from Eastern Ontario where another *Vaccinium* species, lowbush blueberry, was slow to recolonize areas previously treated with hexazinone (Lapointe and Rochefort, 2001), colonization of a bare surface by young cranberry vines is inhibited by dichlobenil applications.

Massachusetts cranberry growers often have expressed concerns that annual repeat applications of high rates (approximately 4.5 kg a.i. ha^{-1}) of dichlobenil caused direct vine injury or increased the susceptibility of the vines to environmental or pest stresses. The few available studies on dichlobenil use in cranberry present conflicting results. A study conducted in the mid-

1960s showed that cranberry vines receiving four annual spring applications of 3.36 kg a.i. ha^{-1} dichlobenil had the highest yield (in three out of four years) compared to both untreated plots and plots receiving 4.5 kg a.i. ha^{-1} of the herbicide (Demoranville and Devlin, 1969). However, an in-house industry memorandum indicated that data from the first year of a 3-yr replicated study predicted a linear relationship of decreasing cranberry fruit set and size with increasing rates of dichlobenil (Kusek and Wick, 1991). Unfortunately, subsequent reports from this study could not be located. Demoranville and Devlin (1969) also evaluated root health by planting cuttings taken from the treated plots (3.4 and 4.5 kg a.i. ha^{-1}) into pots in the greenhouse and subsequently determined percentage poor, fair, or good roots. Even though treated cuttings had fewer healthy roots than untreated cuttings, all treated cuttings had enough roots to predict successful rooting and vine colonization (Demoranville and Devlin, 1969). In contrast, a published abstract noted that cranberry cuttings treated with 3.36, 5.60, and 7.84 kg a.i. ha^{-1} dichlobenil produced no new growth in a greenhouse study (Devlin and Demoranville, 1974), but no subsequent paper containing specific data for this study was identified in the literature. The use of the herbicide has been associated with producing positive fruit attributes. Using the herbicide rates of 0, 3.4, and 4.5 kg a.i. ha^{-1}, the same researchers reported that dichlobenil was associated with an increase in anthocyanin synthesis (Devlin and Demoranville, 1968b; Devlin and Demoranville, 1968a).

The long-term impact of high rates of dichlobenil on cranberry productivity and health remains unclear, and the effects of repeat annual applications of dichlobenil on weed populations in cranberry systems has not been documented. The impacts of low rates of dichlobenil (< 2.0 kg a.i. ha^{-1}), commonly used in current cranberry farming, have not been examined previously. The null hypothesis is that repeat annual applications of dichlobenil do not influence cranberry vitality and weed abundance. The objective of this study was to examine the effects of four years of repeat annual applications of low (1.8 kg a.i. ha^{-1}) and high (4.5 kg a.i. ha^{-1}) rates of dichlobenil on yield components, upright characteristics, and weed abundance in commercial cranberry farms. Data collected to document these effects included: yield component determinants

(percentage flowering uprights and fruit set), commercial acceptability of fruit, cranberry root length, herbicide longevity (as measured by bioassay) and weed species richness and diversity.

Materials and Methods

Field studies were established at two commercial cranberry farms, operated by the same grower, in southeastern Massachusetts during the spring of 1998. The Carver site (CVR) was a 1.7-ha planting (established in 1909) of the cultivar, 'Early Black', and the Rochester site (RCH) was a 3.0-ha planting (established in 1935 and renovated in 1984) of the cultivar, 'Howes'. These sites were selected because the grower opted to manage segments of each farm without the application of any preemergence herbicides. The last broadcast application of dichlobenil to the production area that contained the test plots was made in 1996. Previous research has shown that, through bioassay indicators, active dichlobenil dissipates in approximately 2 months (Sandler and DeMoranville, 1999). The only herbicides applied to the test plots were those specifically used as part of the experiment.

The experiment was conducted as a split-plot, with weediness treatment as the whole plot, replication nested within weediness, and herbicide treatment as the split plot, randomized as a complete block within each replication. In the scope of this design, one set of plots was located in an area of the farm that had high weed density (HW), and one set was located in an area that had low weed density (LW). Weed density was determined by making a visual, qualitative assessment of the farm area for number of weeds species present and the overall weed coverage. The study site did not have an adjacent area that was weed-free, thus only two weed abundance treatments were included in the experiment.

In each location, herbicide treatments were arranged in a randomized complete block design, consisting of four replicates of three treatments. HW and LW areas were specifically selected such that these two groups of 12 plots would be as close to each other as possible. Each

plot was 1.5 m by 6.1 m. Within both high-weed and low-weed locations, individual plots were spaced at least 4.6 m from each other, and complete rows were at least 9.2 m apart. For the next 4 years, plots were treated with one spring application of dichlobenil at the rates of 1.8 kg a.i. ha^{-1} (low rate) or 4.5 kg a.i. ha^{-1} (high rate), or left untreated.

Applications of 4.5 kg a.i. ha^{-1} dichlobenil were made on 12 Apr. 1998, 19 Apr. 1999, 7 Apr. 2000, and 17 Apr. 2001, and applications of 1.8 kg a.i. ha^{-1} dichlobenil were made on 29 Apr. 1998, 3 May 1999, 15 May 2000, and 10 May 2001. Chosen rates and timings were based upon current management recommendations for weed control in commercial cranberry (Sandler, 2003). The herbicide was applied as uniformly as possible utilizing a hand-held plastic shaker with a screw lid (approximate dimensions: 85 mm height, 60 mm diameter width, and pore diameter of 2 mm, with a range of 90 to 95 pores per lid). The shaker was held at a distance of approximately 30 cm from the vine canopy during the delivery of the herbicide. Though wind speed varied for the application dates over the course of the experiment, applications were made when the wind speed was less than 1.8 $m \cdot s^{-1}$. The herbicide was watered in immediately after application via conventional irrigation systems utilized in cranberry production that consist of equally spaced sprinkler heads fixed upon short risers (Spear, 1997) or by hand-held sprinkler cans (RCH 1999 only). Approximately 38,050 $L \cdot ha^{-1}$ water was delivered to both test areas after every application in all years of the study.

Upright Evaluation

To evaluate overall plant health and productivity, upright samples were evaluated from the treated plots. Percentage of flowering uprights (U_F) and percent fruit set are important indicators of yield (Eaton and Kyte, 1978). Vine samples were collected periodically from every plot by excising all uprights close to the bog surface within a 180-cm^2 area. Sampling templates were "rings" made by cutting 15-cm diameter PVC pipe into 2.5-cm wide bands. A ring was

randomly placed into a plot (avoiding sprinkler heads and previously established problem spots such as bare patches) and was positioned as close to the bog surface as possible. Conventional hand clippers were used to cut the uprights. Initially, cuts were made around the entire inner perimeter to permit collection of runners that were passing through the area of the ring. The uprights were then held together and clipped as close as possible to the bog surface. The samples were placed into small resealable plastic bags and transferred to the freezer for storage at -20 °C until evaluations were performed. Sample collection dates were as follows: 9 June 1998 (single sampling date); 3 June, 7 Sep. (CVR), and 10 Nov. (RCH) 1999; 30 May, 5 Sep. (RCH), and 8 Sep. (CVR) 2000; and 21 June and 24 Aug. 2001.

Uprights collected in the spring (the single sample collected in 1998 was included in this evaluation) were evaluated for number of flowering (U_F) and nonflowering (U_N) or vegetative uprights (previous and current year), number of runners, and leaf dry biomass. Leaves comprise the majority of new aboveground biomass produced by cranberry vines each year, and new leaves are important for supporting fruit set and sizing (Roper and Klueh, 1994). Uprights were dried for at least 48 hr at 60 °C. The leaves then were removed from the woody portions of the upright and leaf dry biomass was recorded (Eaton et al., 1983).

Total number of uprights (U_T) was obtained by summing flowering and vegetative uprights, and percentage flowering uprights ($\%U_F$) was calculated. Initial upright density was determined by counting the number of woody uprights (old growth) collected from within the ring template and expressed per m^2. For the current year evaluation, the new growth was usually expanded enough to determine reproductive status. However, newly expanded uprights (reproductive status unknown), and uprights with terminal buds or dead tips were included in the count to tabulate the total number of new uprights in the spring sampling. The absolute number of new uprights may not give a correct assessment of treatment effects as the number of old uprights can vary across the bog due to many factors other than treatments (C.J. DeMoranville, personal communication). To evaluate treatment effect on any inherent upright density variation

that may have been present, percentage change in upright density was calculated by dividing the difference between the total number of new and old uprights by the original number of old uprights, multiplied by 100.

For the fall sampling (years other than 1998), $\%U_F$ was determined based on the status of the current year's growth. Since terminal buds in cranberry are formed in late summer and are considered to be good indicators of yield potential (Lacroix, 1926), the number of uprights with new terminal buds was also determined. Numbers of pedicels (indicative of unfertilized flowers) and fruit were determined for uprights collected within each ring template to calculate percentage fruit set. In 1999, the fall vine samples from the RCH site were collected after commercial harvesting, and no fruit were present for evaluation. As with the spring samples, uprights from the fall samples were dried for at least 48 hr at 60 °C. The leaves were then removed from the woody portions of the upright and leaf dry biomass was recorded.

Cranberry Root Length Estimates

Root lengths were measured using a 30-mm diameter metal soil sampling tube that had a length of 31 cm. The tube had an open portion of the cylinder at the lower end that permitted direct measurement of the roots upon extraction of the soil core. Root lengths were measured three times during the course of the study: 14 June, 5 Sep. (RCH) and 11 Sep. (CVR) 2000 and 2 Aug. 2001. Four 15-cm deep soil cores from each plot were taken, and root lengths were measured and averaged to generate a value for the plot. The thickness of the root layer was measured with the core in place in the sampling tube (Lampinen, 2000). Root length (a field estimate of rooting depth) was determined to be the distance from the soil surface to the end of root extension.

Yield

Plots were harvested in September each year. Specific harvest dates were as follows: 15 Sep (CVR), 25 Sep. (RCH), 1998; 14 Sep. (CVR), 27 Sep. (RCH), 1999; 8 Sep. (CVR), 26 Sep. (RCH), 2000; and 11 Sep. (CVR), 18 Sep. (RCH), 2001. A 900-cm^2 area was selected randomly for each replicate, and all berries within this area were collected. Fruit were stored and evaluated according to conventional practice (Sandler, 1995; Caruso, 1999). The fruit were stored at 5 °C in paper bags and visually evaluated for field rot within 1 week. To approximate the size of berries collected during commercial harvesting, very small fruit were removed prior to evaluation. The samples were passed over a 5.6-mm sieve (U.S.A. Standard Testing Sieve, No. 3.5, Fisher Scientific Co., Mentor, Ohio) to eliminate nonpollinated, undersized, and aborted fruit.

Rotten and damaged fruit sorted during the initial evaluation were designated as field-rotted and damaged berries, respectively. Fruit that were infected by fruit rot fungi, exhibited signs of physiological damage, damaged by insects or weather, or bruised by mechanical means were deemed unusable (Eck, 1990). For each category, berries were assessed, counted, and weighed (pooled sample). The berries were placed into small (11 x 18 cm) bags made from fiberglass insect screening. Silicone caulking was used to seal the screening on three sides, leaving the fourth side open. A paper clip was used to secure the bag after the fruit were placed inside. The commercial storage practice of keeping healthy, damaged, and rotten fruit together until sorted for packaging was simulated by placing the damaged and rotten fruit into the paper bag with the healthy fruit. The healthy fruit were in proximity of the unusable fruit, but the need to re-count the same unusable fruit during the storage rot evaluation was eliminated due to the screen bag. All fruit were placed back into cold storage at 5 °C in open paper bags. To approximate the duration of commercial cranberry storage, the percentage of the fruit with storage rot was determined 8 weeks postharvest.

Percentage unusable yield was determined by dividing the total number of berries that were rotted or damaged at harvest (or 8 wk later) by the total number of berries collected, multiplied by 100. Weight of unusable fruit was determined by summing the actual weights of all rotted and damaged fruit collected from the sample area. Total yield, an estimate of crop potential (useful if exterior factors, such as weather or insects affect yield), was calculated based upon the total number of all berries (damaged, rotten, and healthy), assuming 1 g per berry (Fellers and Esselen, 1955; DeMoranville, 1992). The actual weight per healthy berry could be used to determine total yield, but was not the method chosen for this study. Marketable yield was determined by the weight of all healthy berries collected from the sample area.

Vegetation Surveys

Utilizing a square-meter quadrat, surveys of the vegetation in the treated and nontreated areas were conducted on an annual basis. The survey dates for this study were: 19 June 1998 (CVR), 1 July 1998 (RCH), 10 Aug., 1999, 18 Aug. 2000, and 6 Aug. 2001. Presence of each plant species was estimated visually, using percentage estimate of coverage by the plant species. Adapted from other authors (Barbour et al., 1987; Kent and Coker, 1992), the following nine estimate groupings were used: <1%; 1-5%; 6-10%; 11-25%; 26-40%; 41-60%; 61-75%; 76-90%; and >90%.

Two observers recorded their estimations independently. Resolution of discrepancies, spaced by more than one group, was the average between the groups. Resolution of discrepancies for adjacent groups was obtained by re-evaluation. Most species were identified in the field or brought to the lab and identified through use of common flora (Newcomb, 1977; Gleason and Cronquist, 1991; Uva et al., 1997; Holmgren, 1998). Unknown species were sent to the UMass Herbarium and identified by Dr. Karen Searcy.

To facilitate analysis with the PC-ORD software (MjM Software Design, Gleneden Beach, OR), percentage cover (%Cover) ranges were assigned integer values. Integer values are equivalent to cover class values (CCV). Data were analyzed with PC-ORD to obtain species richness (number of species present) and the Shannon diversity index. The diversity index (Shannon and Weaver, 1949) is defined as:

$$H' = -\sum_{i=1}^{S} p_i \log p_i \qquad \text{(Equation 2.3)}$$

where S = number of species and p_i = the proportion of individuals or the abundance of the *i*th species expressed as a proportion of total cover, and log = log $base_n$ (log_{10} is most commonly used, but other bases are acceptable).

Soil Samples and Bioassays

A seedling bioassay using alfalfa (*Medicago sativa* L.), a dichlobenil-sensitive plant, was employed to determine root growth response on herbicide-treated soil. Soil samples were collected using a 20-mm diameter soil probe. At each sampling date, four cores (to a depth of 10 cm) per plot were taken, combined into a composite sample, and placed in a 14 x 21-cm resealable sample bag. Bags were stored at 7 °C for 1 to 2 d until the bioassay was performed. In 1998, soil was collected on: 4 May, 21 May, 3 June, 25 June, 15 July, 5 Aug. (CVR), and 26 Aug. (RCH). In 1999, soil was collected: 7 May, 24 May, 15 June, 6 July, and 27 July. In 2000, sampling dates were: 30 Mar., 8 May, 30 May, 19 June, 10 July, and 8 Aug. (CVR only), and in 2001, sampling dates were 16 Apr., 16 May, 6 June, 28 June, 18 July, 8 Aug. (RCH), and 16 Aug. (CVR). In Years 1 and 2, the first soil samples were collected 3 to 4 wk after each herbicide treatment. In Years 3 and 4, pre-application soil samples were collected from all treatments. In Year 4, five post-treatment samples were collected for the untreated and high-rate herbicide plots.

Due to a miscommunication, only four samples were collected post-treatment from the low-rate herbicide plots (samples were not collected on 16 May 2001).

The general technique for a seedling bioassay to determine activity of herbicide residues (Murray and Santelmann, 1980; Parker and Ogg, 1990; Norman and Patten, 1995; O'Donovan et al., 1996) was modified slightly. This modification, published previously (Sandler and DeMoranville, 1999) was utilized in this study and is detailed as follows. Three to 4 d prior to any sampling date, ~ 5 g of alfalfa (*Medicago sativa* L.) seeds were placed in a small, round Petri dish and submerged in water for ~ 5 min. Excess water was drained from the dish. The seeds were then transferred onto moist filter paper in a clean glass Petri dish, sealed with opaque laboratory film and incubated at 24 °C. The combined core sample was placed into a square Petri dish (Integrid 100 x 15 mm; Becton-Dickinson, Lincoln Park, N.J.) and distributed uniformly, completely filling the dish.

For each sampling date, six germinated alfalfa seedlings were taken from the seeding plate and uniformly spaced on the surface of the core sample in each square Petri dish. The seedlings were oriented with the cotyledons ~ 5 mm from the top of the dish and all roots extending towards the bottom. The lid was carefully placed on top of the seedlings to minimize subsequent movement. The initial root length was measured, recorded, and marked on the Petri dish cover. All dishes were incubated in a vertical position (to permit root elongation) for 7 d, after which root length of each seedling was measured. In Year 1, seedlings were incubated at ambient temperature, which ranged from 22 to 25 °C. In all other years, seedlings were incubated at a constant temperature of 24 °C. Treatment effect on root length after 7 d was determined by subtracting the original root length of each seedling from its final length. The six values obtained from each dish were averaged to obtain a value for root growth from each replicate dish. Eight replicates of six seedlings were plated for each treatment.

Statistical Analyses

The experimental design for this study can be described as a split-plot design with weediness as the whole plot, replication nested within weediness treatment, and herbicide treatment as the split plot, randomized within each replication. F-tests (via Proc Mixed and Slice option) were used to test for main effects and their interactions for all data.

ANOVA model assumptions were tested through residual analyses (Bowley, 1995). SAS code including Proc GLM, Proc Plot, and Proc Univariate was used to calculate and plot the pattern of the residuals. The Shapiro-Wilk statistic was used to test if the error distribution departed from normality. Several parameters had to be transformed to meet model assumptions and are mentioned specifically in the discussion. Analyses were performed on the transformed data and the means of the transformed data. To facilitate reader understanding, means were back-transformed to their original units for tabular and figure presentation.

SAS Version 8.2 (SAS Institute, Cary, NC) was used as the statistical analysis software package. P-values for the various parameters and interactions are listed in Appendices A.1 through A.6. If site*treatment interactions were not significant ($P>0.05$), data from CVR and RCH were pooled for further analysis. For spring upright evaluation, total upright (old growth), percentage flowering uprights (new growth), leaf dry biomass, and change in upright density data were pooled. For the fall upright evaluation, only percentage flowering upright data were pooled. All site data for harvest and diversity parameters except percentage unusable yield and Shannon diversity index, respectively, were pooled for analysis. Cranberry root length and alfalfa root length (bioassays) data were pooled. Similarly, if year*treatment interactions were not significant, year data were pooled. These occurrences are mentioned specifically in the discussion.

Computed means for analyzed parameters are presented in the tables and treatment effects are presented in figures. Year was significant for almost every parameter measured in this

study, as would be expected when a fruit crop exhibits alternate bearing (Eaton, 1978; Strik et al., 1991; Roper et al., 1993). Year*treatments interactions were significant for some parameters and related tables and figures show data by year. When the analyses indicated significance between treatments (weeds and/or herbicide treatment), data were subsequently plotted in graph form. Orthogonal polynomial contrasts were used to describe the best-fit relationships for significant continuous main effects and their interactions. Significant effect of weed presence was evaluated by F-tests generated with the SLICE option in Proc Mixed (SAS Institute, 2001). Dunnett's mean separation test was used to compare alfalfa root lengths grown on soil collected from plots that received herbicide application to the untreated control plots.

Vegetation survey data were first analyzed using a multivariate software package, PC-ORD, Version 4.2 (MjM Software Design, Gleneden Beach, OR). This software was used to generate basic descriptive statistics and diversity measures including species richness, and Shannon diversity index. Data conformed to ANOVA model assumptions. Parameters were analyzed in SAS, utilizing PROC MIXED to determine treatment effects.

Results and Discussion

Upright Evaluation

Spring Upright Evaluation

Previous research has shown that the primary indicators of successful yield in cranberries are the percentage U_F and fruit set in the production area (Eaton and Kyte, 1978). Upright density of the old growth was determined by counting the number of woody stems present per vine sample collected from the ring templates. The number of uprights (per unit area) from the old growth is representative of the density of persistent woody uprights that remained alive after the winter. These older woody stems bear the new upright growth upon which fruit may be produced

in any given year. ANOVA indicated that neither weediness nor herbicide application affected the total number of uprights in the old growth in any given year or at the end of the 4-yr period (Table 2.1). In other words, treatments did not adversely or positively affect the original stand density of the cranberry planting.

Percentage U_F data were transformed using arcsine-square root to meet model assumptions. At the end of four years of study, vines in the LW areas had a higher percentage U_F (Table 2.2) compared to vines in the HW area. However, the effect of weediness varied by year. This is likely due to the alternate bearing habit of cranberry (Eaton, 1978; Roper et al., 1993) or environmental factors, rather than annual changes in the weed pressure. F-tests indicated LW areas had a higher percentage U_F (Figure 2.1) in 1998 and 2001. Herbicide rate had no effect on percentage U_F.

Site and treatment interacted to affect total number of uprights (U_T) of the new growth, so data are presented by site (Table 2.3). These data were log-transformed to meet model assumptions. Weediness and herbicide rate interacted to affect U_T at CVR. No significant differences were noted at RCH. Data for the four-year study at CVR were pooled as year*treatment interactions were not significant ($P>0.05$). Partitioning the sum of squares indicated significance for the untreated plots only (Figure 2.2). Plots located in the HW location had a higher U_T than in the LW section. Since the $\%U_F$ was higher in the LW plots (Table 2.2, Figure 2.1), the increase in U_T in the HW plots may be ascribed to an increased production of vegetative uprights. U_T was statistically similar for the HW and LW plots treated with low-rate and high-rate applications of dichlobenil. This would indicate the vines treated with either rate of the herbicide could produce equivalent numbers of new uprights whether growing amongst weeds or not.

The presence of weeds affected the percentage change in upright density (ΔU_D) (Table 2.4, Figure 2.3). Year*treatment interactions were $P>0.05$, thus year data were pooled. ΔU_D was

higher in plots located in the HW area compared to vines collected from the LW area. Cranberry vines are alternate bearing (Strik et al., 1991; Roper et al., 1993), and produce a mixed composition of flowering and vegetative uprights in any given year. As with U_T, the increase in U_D in the HW plots may be ascribed to an increased production of vegetative uprights (LW plots had a higher U_F). Herbicide application had no effect on ΔU_D.

Leaf dry biomass data were log-transformed to meet model assumptions. Mean leaf dry biomass was not affected by weediness or herbicide rate (Table 2.5). Leaves are known to be important constituents affecting yield and overall plant health (Roper and Klueh, 1994). Repeat herbicide applications did not have a deleterious effect on leaf biomass for vines collected in the spring.

Fall Upright Evaluation

Uprights were evaluated in the latter part of the season to determine $\%U_F$, U_T, percentage fruit set, number of new terminal buds, and leaf dry biomass. Fall samples were collected from 1999 through 2001; only one sampling date (grouped with the spring samples) occurred in 1998. ANOVA indicated no significant effects of weediness or herbicide rate on the $\%U_F$ for vines collected in the fall (Table 2.6). In contrast, spring-collected vines from LW areas had higher U_F than vines collected from HW areas in two out of four years. Even though initial U_F may be higher in some years, other factors, such as fertilizer or cultural practices, may play a more important role in end-of-season U_F production than weed presence (Eck, 1976; Strik and Poole, 1991).

The effect of weed presence on U_T varied at each site. The effect of weediness on U_T (Table 2.7) varied by year at RCH. U_T was greater in the LW portions of the bog at RCH in 2000 compared to the HW in the plots (Figure 2.4). No treatment effects were seen at CVR. The effect of treatment was weak, and the response in one year at one site is likely due to chance. Overall,

weed presence had minimal effect on U_T for both spring and fall samples. Herbicide treatment had no effect on U_T at either site.

The effect of weediness on leaf dry biomass (data log-transformed) also varied by site (Table 2.8). However, no treatment effects were seen at RCH and the effect of weediness was significant in one year only at CVR. In 2001, leaf dry biomass was higher in the HW plots compared to the LW plots (Figure 2.5). The increase in dry biomass may be due to the higher upright density recorded in the HW locations at CVR (Table 2.7). Vines in the HW areas may be putting more resources into vegetative growth (lower $\%U_F$ seen in HW areas). Similar to the spring sampling, herbicide application did not adversely affect cranberry leaf biomass production collected in the fall.

Site*treatment interactions were significant for number of new terminal buds (data transformed by square root-arcsine) and percentage fruit set, and data were analyzed by site (Table 2.9). The terminal bud is considered to be a mixed bud, containing floral initials and a vegetative meristem (Eck, 1990). New buds are typically set in August for the following year and can be an indicator of plant health and yield potential (Lacroix, 1926). Weediness was the influential treatment at RCH, and herbicide affected the number of terminal buds at CVR. The effect of weediness varied with year at RCH (Figure 2.6). Higher numbers of terminal buds were seen in the LW areas in 1999 and 2000. This trend was not seen in 2001 as the number of terminal buds was statistically similar for HW and LW locations.

At CVR, the effect of herbicide on the number of terminal buds varied by year. Significant effects were noted in 2000 and 2001. Orthogonal polynomial contrasts indicated that the best-fit relationship was quadratic ($P=0.013$) for 2001 (Figure 2.7). The best-fit relationship in 2000 was weakly quadratic ($P=0.080$). Combining weed treatments, plots receiving the low-rate herbicide treatment had the highest number of buds in 2000 and 2001 (2,450 and 2,220 buds$\cdot m^{-2}$, respectively). The effect of herbicide cannot be described consistently. In 2000, the

next highest number occurred in the untreated plots (2,160 buds•m^{-2}); in 2001, the next highest number occurred in the high-rate herbicide plots (1,760 buds•m^{-2}).

Weed presence affected the percentage of fruit set at CVR. No treatment effects were noted at RCH. For CVR, the absolute value of percentage fruit set varied by year, but the year*weeds interaction was not significant. Averaged over the four years, percentage fruit set was higher in plots located in the LW area compared to fruit set in the HW area (Table 2.9, Figure 2.8). Notably, herbicide rate had no effect on percentage fruit set.

Yield

No significant treatment effects were noted for weight per healthy berry in any year (Table 2.10). Two yield parameters were calculated: total yield and marketable yield. The yield parameters were square-root arcsine transformed for data analysis. Total yield (weight of all fruit assuming 1 g per berry) was affected by weediness (Table 2.11). Since the interaction of year and treatment was nonsignificant, graphical data are presented with years pooled. Vines in the LW area had more total yield (potential yield) than vines in the HW area (Figure 2.9). Y_M was determined by converting the weight of all healthy berries collected from the sample area to Mg per hectare. Again, more marketable yield was produced in the LW location as compared to vines in the HW area (Table 2.11, Figure 2.9). Repeated annual applications of dichlobenil, whether applied at low or high rates, did not adversely affect yield.

The effect of weediness on commercially unusable yield varied by site (Table 2.12). Percentage Y_U data were log-transformed to conform to model assumptions. A higher percentage unusable yield was produced in the HW plots at CVR (Figure 2.10); no treatment effects on percentage unusable yield were seen at RCH. This may be due to cultivar differences (CVR-Early Black and RCH-Howes). Early Black vines tend to produce denser canopies than Howes

vines and may create micro-environments that make fruit more susceptible to fruit and physiological rot (Caruso and Ramsdell, 1995; Caruso et al., 2000).

Cranberry Root Length

Cranberry root length (Table 2.13) was not affected by weediness or herbicide rate. The effect of the interaction of weediness and herbicide varied by date of sampling (Figure 2.11). Results were mixed. No treatment effects were seen for the first sampling date (June 2000). Cranberry root lengths were greater in the LW location as compared to the HW location in plots treated with the maximum rate of dichlobenil (September 2000) or left untreated (August 2001). No consistent trend on root length (adverse or positive) was seen. It is probable that more frequent sampling would help delineate treatment effects. Further work is needed to determine if herbicide application and/or weed presence adversely or positively affects cranberry root length.

Vegetation Surveys

To facilitate analysis with the PC-ORD software, % cover ranges were assigned integer cover class values (CCV) (Table 2.14). All vegetation parameters met model assumptions without transformation. All identified plant species, along with the %frequency and maximum CCV were documented over the course of the study for CVR and RCH (Tables 2.15 and 2.16, respectively). If known, common names were also included. Twenty-two different weed species were identified at Carver, and 13 different weed species were identified at Rochester.

Apios americana Medikus. and *Euthamia tenuifolia* (Pursh) Nutt. increased in coverage over the 4-year period at CVR. *A. americana* recorded a maximum CCV of 9 in 2000, the highest for any weed species. *A. Americana* and *E. tenuifolia* were the most frequently documented weed species at CVR (Table 2.15). *Cyperus dentatus* Torr., *E. tenuifolia*, and

Leersia oryzoides (L.) Sw. increased in coverage over the 4 years at RCH (Table 2.16). *E. tenuifolia* and *L. oryzoides* had the highest CCV (maximum value of 7) of the weed species identified at RCH. *E. tenuifolia* and *Viola lanceolata* L. were the most prevalent weeds, occurring in almost every plot.

Response of percentage weed cover, when sorted by occurrence in the HW and LW areas, differed at each site (Tables 2.17 and 2.18, respectively). At CVR, *A. americana* was present in the HW areas only and increased in coverage from <1% to 25% during the study. *E. tenuifolia*, though present in LW and HW areas, increased from <1% to 4% in the HW areas. More species were documented in the HW area (N=19) than in the LW area (N=10). In contrast, the number of species in the HW and LW area at RCH only differed by one (Table 2.18). *E. tenuifolia* increased from 14% to 38%, and *Salix* sp. went from undetected to 7% coverage in the HW area. *C. dentatus* decreased in %cover in the HW area and increased in the LW area.

ANOVA indicated weediness affected %Cover (Table 2.19), site data pooled. In all years, LW plots had lower percentage weed cover than HW plots. %Cover increased in the HW and LW plots from the inception of the study to the end. Notably, no effect of herbicide treatment was seen for %Cover for the weed species.

Data in Table 2.19 indicated that coverage by weeds in the LW plots was progressing more slowly than in the HW plots; higher %Cover was also noted in the untreated plots (HW compared to LW areas). To determine the effect of treatment on these trends, the percentage change in %Cover from 1998 to 2001 was calculated and analyzed for treatment effects (Appendix A.4). Site*treatment interactions were not significant (P>0.05), so site data were pooled. Initial weed density significantly influenced final weed density. Percentage change in weed coverage over the course of the study was lower in the LW plots than in the HW plots (Figure 2.12). Herbicide application appeared to have an effect on percentage change in weed cover, but large variability within herbicide treatments precluded finding statistical differences.

Averaged across herbicide rates, HW plots had an increase in weed cover (+40%), while the LW plots showed a minimal decrease (-1%).

Species richness (number of species in the sample area) decreased slightly (P=0.049) as herbicide rate increased (Table 2.20). Species richness was lower in the LW plots compared to the HW plots. Orthogonal polynomial contrasts indicated the best-fit relationship was linear; species richness declined as herbicide rate increased (Figure 2.13).

The effect of weediness on Shannon diversity index, H′, varied by site (Table 2.21). Diversity was lower in the LW plots compared to the HW plots at CVR, irrespective of herbicide application (Figure 2.14). No differences were noted at RCH. For relative comparison to other plant communities, the values in this study indicated plant communities of minimal plant diversity (values <1). Values for Shannon index varies from 0 (community of one species) to values of 7 or more in very rich plant communities (DeJong, 1975). Species diversity was not affected by herbicide application. Even though species richness declined slightly with herbicide rate, the overall effect of herbicide rate on these vegetation parameters was minimal.

Bioassays for Herbicide Longevity

Comparisons of root length of alfalfa seedlings were used as a bioassay to estimate the length of herbicide activity after application (Table 2.22). ANOVA indicated no effect of weediness or any other interaction with weediness. For simplicity of graphical presentation, data for alfalfa root lengths were averaged for LW and HW plots for each herbicide rate at each date (Figure 2.15). Root lengths were similar, when compared to the untreated (according to Dunnett's mean comparison test; Appendix A.5), by sampling date 15 July 1998, 27 July 1999, 10 July 2000 and 28 June 2001 for the high-rate herbicide treatment (mean = 89.2 days after treatment or DAT). Though no differences were seen at RCH, root lengths in the last sampling date in 2000 were shorter than the untreated at CVR. For the low-rate herbicide treatment, root

lengths were similar to the control by 25 June 1998, 6 July 1999, 30 May 2000, and 18 July 2001 (mean = 53.0 DAT). Since approximately three weeks elapsed between each sampling date, similarity in root lengths may have occurred up to approximately 20 days sooner than detected by the sampling technique.

The purpose of the bioassay was to allow documentation of herbicide activity after application to the study plots, not to precisely quantify the exact length of herbicide activity. Nonetheless, these data correspond well with previously published information (Sandler and DeMoranville, 1999), which found herbicide activity was maintained for 2 months with an application rate of 1.8 kg a.i. ha^{-1}. It is not known how activity of dichlobenil against alfalfa roots relates to efficacy of control for target cranberry weeds.

Conclusions

Despite grower concerns about the detrimental effect of long-term use of dichlobenil, these studies indicated minimal negative impact of repeat annual applications. Herbicide application did not adversely affect upright productivity, cranberry biomass production, or percentage fruit set. Repeat annual applications of dichlobenil, whether applied at low or high rates, did not adversely affect any yield parameters. This is in accordance with previous work where applications of dichlobenil did not affect various growth parameters on apples (Heeney et al., 1981b; Hogue and Neilsen, 1988) and on cranberries (Devlin and Demoranville, 1973). Weed populations in HW areas showed a greater increase in percentage coverage compared to weed populations present in LW areas. Herbicide application appeared to decrease the percentage cover by weed species, but due to wide variability of the data, the trend could not be substantiated statistically. Plots located in the LW area treated with low and high rates of dichlobenil showed an actual decrease in percentage weed cover (rather than just a smaller increase) compared to those in the HW area.

The effect of weed presence on upright parameters was variable. Though one year was statistically significant on one site, weediness had no overall effect on leaf biomass. U_T varied with cultivar (site) and treatment, but no consistent trend was seen. In the spring, Early Black (CVR) untreated vines in the HW locations produced a higher U_T than untreated vines located in the LW area. No treatment interaction was present at RCH. In only one out of three years, vines collected from the LW area at RCH had a higher U_T than HW in the fall; no treatment effects were noted for fall samples at CVR. In 2 out of 4 years, vines collected in the spring from the LW areas had a higher $\%U_F$, an important indicator of yield, than vines in HW areas. This difference, however, was not documented in the fall sampling. Notably, herbicide application did not adversely affect upright productivity.

Different weed species are known to variably impact cranberry crop productivity (Else et al., 1995). The two research locations utilized in this study contained a certain complex of weed species. Weed communities in commercial cranberry production areas are known to vary from site to site (Sandler, unpublished). Extrapolation of data from this study must consider that other factors such as cranberry variety, management practices, site characteristics, as well as weed community composition, may influence response trends for cranberry yield components.

The presence of weeds, rather than herbicide application, was the important determinant of yield performance. This finding is supported by previous research that showed yield and yield components were reduced in weedy areas (Yas and Eaton, 1982). Vines in HW areas produced less total and marketable yield, and put more resources into producing fruit that would be considered commercially unacceptable. Herbicide application had no adverse effect on yield. Further work is needed to determine if herbicide application and/or weed presence adversely or positively affects cranberry root length. Results from this study suggest that repeat annual applications of dichlobenil to commercial cranberry beds may be considered as part of a viable integrated weed management program with minimal long-term risk.

Table 2.1. Spring sampling. Upright density of old growth of cranberry vines present in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	Old growth: Total uprights ($1000 \cdot m^{-2}$)[z] 1998	1999	2000	2001	Mean
0	HW	7.58	5.16	8.21	7.69	7.16
	LW	6.27	6.94	8.25	8.44	7.47
1.8	HW	6.92	6.73	6.84	7.19	6.92
	LW	8.40	6.78	7.58	8.08	7.71
4.5	HW	7.59	7.15	9.66	8.81	8.30
	LW	8.29	6.40	8.27	8.45	7.85

[z]ANOVA indicated no significant effects of treatment.

Table 2.2. Spring sampling. Percentage of flowering uprights of new growth of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	New growth: Flowering uprights (%)[z] 1998	1999	2000	2001	Mean
0	HW	10.4	16.0	14.4	18.7	14.8
	LW	17.3	16.3	15.5	24.8	18.4
1.8	HW	9.3	17.6	14.7	18.9	15.1
	LW	18.9	16.5	20.0	28.1	20.9
4.5	HW	10.6	15.3	13.1	18.4	14.3
	LW	14.1	16.2	14.1	28.0	18.1

[z]ANOVA indicated the effect of weed presence on percentage flowering uprights varied by year ($P=0.038$), with significant differences in 1998 ($P<0.001$) and 2001 ($P=0.001$).

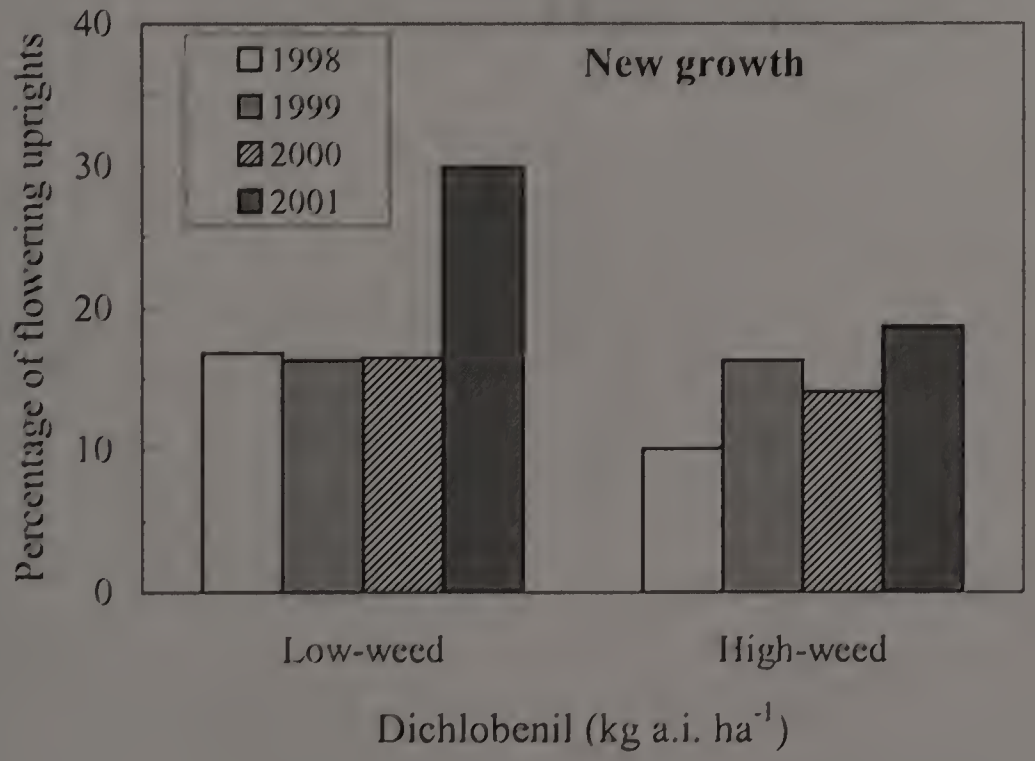

Figure 2.1. Spring sampling (new growth). Interaction of weediness and year on percentage of flowering uprights collected from plots treated with various rates of dichlobenil (N=24). Significant differences occurred between LW and HW treatments in 1998 and 2001.

Table 2.3. Spring sampling. Total upright density of the new growth of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

			New growth				
	Rate	Weed	Total uprights ($1000 \cdot m^{-2}$)[z]				
Site	(kg a.i. ha^{-1})	status	1998	1999	2000	2001	Mean
CVR	0	HW	19.7	12.3	16.0	17.1	16.3
		LW	15.1	16.8	11.0	15.4	14.6
	1.8	HW	14.9	15.3	12.4	12.9	13.9
		LW	15.7	15.2	13.4	16.6	15.2
	4.5	HW	15.5	19.0	18.0	16.6	17.3
		LW	18.6	15.6	13.8	15.5	15.8
RCH	0	HW	9.2	7.4	10.1	10.1	9.2
		LW	7.9	9.1	11.9	9.6	9.6
	1.8	HW	9.1	9.4	8.6	10.9	9.5
		LW	9.4	8.0	9.9	8.8	9.0
	4.5	HW	11.5	9.6	11.0	11.5	10.9
		LW	8.2	8.6	11.5	9.5	9.5

[z]Weeds and herbicides interacted to affect the total number of uprights at CVR (P=0.022).

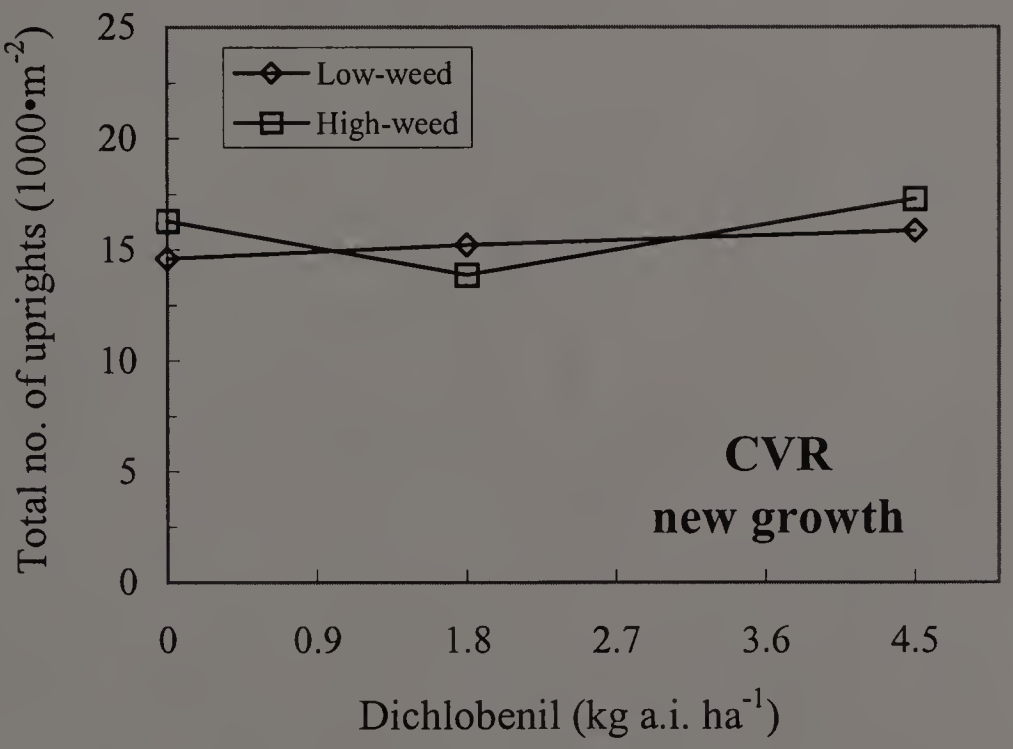

Figure 2.2. Spring sampling (new growth). Interaction of weediness and herbicide application on the total number of uprights collected from plots (CVR) treated with various rates of dichlobenil for four years (N=16). Significant differences occurred between LW and HW treatments at 0 $kg \cdot ha^{-1}$ rate.

Table 2.4. Spring sampling. Percentage change in upright density in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	Percentage change in upright density per m^{2z}				
		1998	1999	2000	2001	Mean
0	HW	85.6	128.8	57.6	74.4	86.6
	LW	111.4	57.3	39.4	47.2	63.8
1.8	HW	70.3	81.2	56.8	67.4	68.9
	LW	48.1	73.8	53.8	53.6	57.3
4.5	HW	78.2	98.7	51.8	65.0	73.4
	LW	59.5	87.1	58.3	46.6	62.9

[z]ANOVA indicated an effect of weeds on change in upright density (P=0.037).

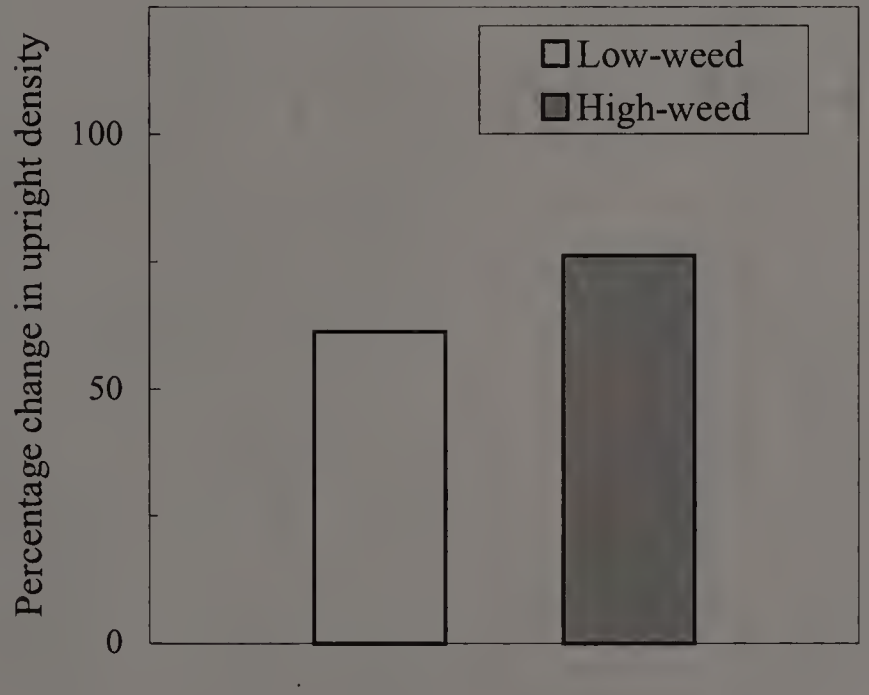

Figure 2.3. Spring sampling (new growth). Effect of weediness on the percentage change in upright density in plots treated with various rates of dichlobenil for four years (N=96).

Table 2.5. Spring sampling. Leaf dry biomass of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	Leaf dry biomass ($kg \cdot m^{-2}$)[z]				
		1998	1999	2000	2001	Mean
0	HW	0.66	0.39	0.59	0.58	0.56
	LW	0.57	0.48	0.49	0.61	0.54
1.8	HW	0.57	0.41	0.45	0.55	0.50
	LW	0.65	0.47	0.43	0.57	0.53
4.5	HW	0.61	0.54	0.58	0.60	0.58
	LW	0.68	0.47	0.42	0.61	0.55

[z]ANOVA indicated no treatment effects on leaf dry biomass.

Table 2.6. Fall sampling. Percentage of flowering uprights of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate	Weed	Flowering uprights (%)[z]				
(kg a.i. ha^{-1})	status	1998[y]	1999	2000	2001	Mean
0	HW	n/a	18.9	27.1	23.2	23.1
	LW	n/a	24.2	24.8	25.9	25.0
1.8	HW	n/a	18.7	29.7	22.5	23.6
	LW	n/a	30.2	22.8	28.6	27.2
4.5	HW	n/a	18.7	26.3	20.3	21.8
	LW	n/a	22.1	25.4	24.2	23.9

[z]ANOVA indicated no treatment effects.

[y]Bi-annual vine sampling began in 1999.

Table 2.7. Fall sampling. Total number of uprights of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

	Rate	Weed	Total no. uprights (1000•m^{-2})[z]				
Site	(kg a.i. ha^{-1})	status	1998[y]	1999	2000	2001	Mean
CVR	0	HW	n/a	9.43	10.78	11.67	10.62
		LW	n/a	9.70	10.46	8.60	9.59
	1.8	HW	n/a	11.78	10.33	12.48	11.53
		LW	n/a	7.66	9.88	8.66	8.73
	4.5	HW	n/a	9.48	9.48	10.32	9.76
		LW	n/a	9.11	11.18	9.31	9.87
RCH	0	HW	n/a	7.05	6.08	6.89	6.67
		LW	n/a	7.52	8.82	6.28	7.54
	1.8	HW	n/a	6.23	5.15	5.97	5.78
		LW	n/a	7.39	6.35	6.48	6.74
	4.5	HW	n/a	5.67	6.70	6.89	6.42
		LW	n/a	7.19	7.74	6.48	7.14

[z]ANOVA indicated the effect of weeds varied by year (P=0.046) at RCH, with significant effects in 2000 (P=0.009).

[y]Bi-annual vine sampling began in 1999.

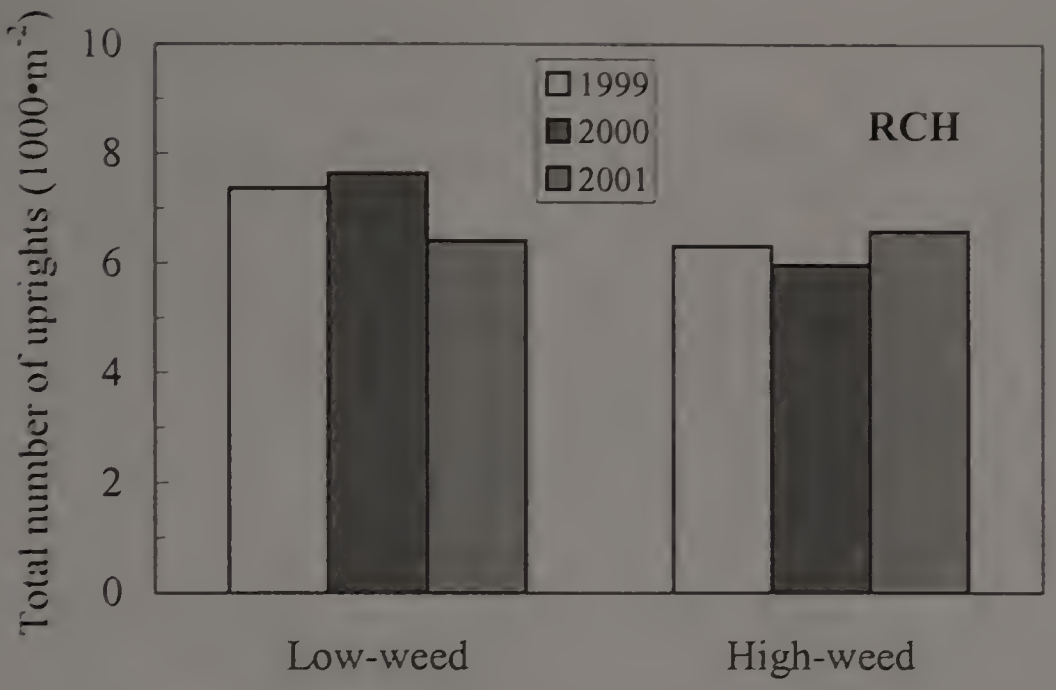

Figure 2.4. Fall sampling. Interaction of weediness and year on total number of uprights collected from plots (RCH) treated with various rates of dichlobenil (N=12). Significant differences occurred between HW and LW in 2000.

Table 2.8. Fall sampling. Leaf dry biomass of cranberry vines in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

Site	Rate (kg a.i. ha^{-1})	Weed status	Leaf dry biomass ($kg \cdot m^{-2}$)[z]				
			1998[y]	1999	2000	2001	Mean
CVR	0	HW	n/a	0.63	0.61	0.78	0.67
		LW	n/a	0.58	0.60	0.52	0.57
	1.8	HW	n/a	0.72	0.55	0.90	0.72
		LW	n/a	0.46	0.57	0.57	0.53
	4.5	HW	n/a	0.54	0.56	0.69	0.60
		LW	n/a	0.58	0.56	0.58	0.57
RCH	0	HW	n/a	0.43	0.37	0.50	0.43
		LW	n/a	0.38	0.53	0.44	0.45
	1.8	HW	n/a	0.36	0.34	0.39	0.36
		LW	n/a	0.41	0.39	0.46	0.42
	4.5	HW	n/a	0.37	0.41	0.63	0.47
		LW	n/a	0.39	0.40	0.54	0.44

[z]ANOVA indicated weeds and year interacted to affect total dry biomass at CVR (P=0.012), with significant differences in 2001 (P=0.001).

[y]Bi-annual vine sampling began in 1999.

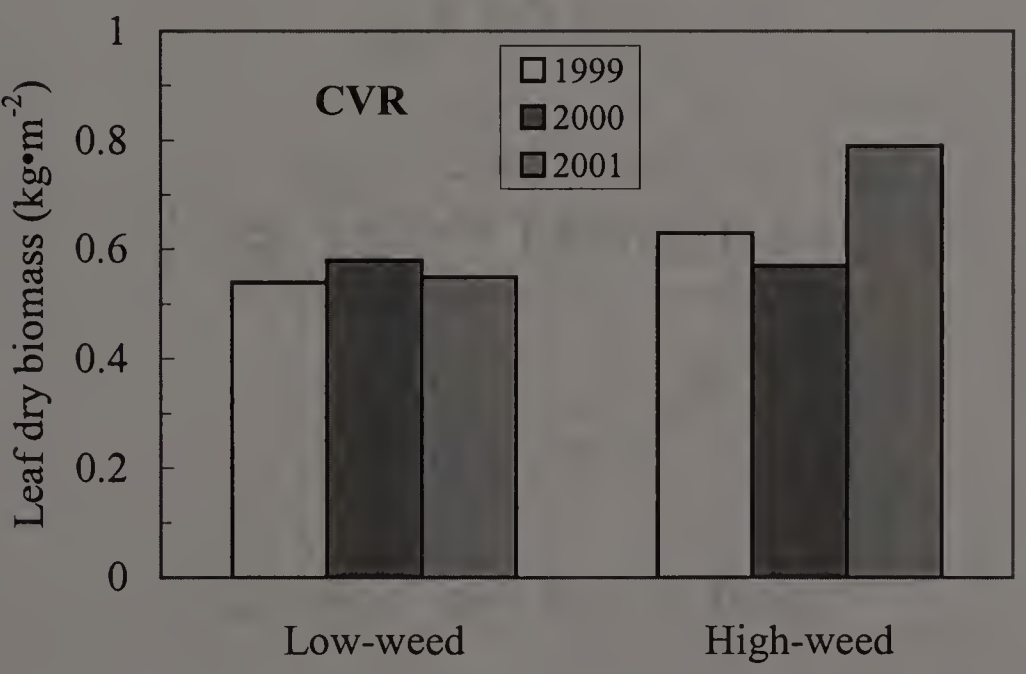

Figure 2.5. Fall sampling. Interaction of weed presence and year on leaf dry biomass from plots (CVR) treated with various rates of dichlobenil (N=12). Significant differences occurred between HW and LW in 2001.

Table 2.9. Percentage fruit set and number of terminal buds of uprights present in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

Site	Rate (kg a.i. ha^{-1})	Weed status	Fruit set (%)[z] 1999	2000	2001	Mean	No. terminal buds (1000•m^{-2})[y] 1999[x]	2000	2001	Mean
CVR	0	HW	27.8	34.1	12.4	24.8	0.89	1.84	1.17	1.30
		LW	29.7	45.1	24.4	33.1	0.86	2.49	1.22	1.52
	1.8	HW	24.8	44.8	11.6	27.1	0.97	2.68	2.72	2.12
		LW	28.7	50.9	28.6	36.1	0.54	2.23	1.73	1.50
	4.5	HW	17.6	43.4	14.4	25.1	1.23	1.19	1.76	1.40
		LW	31.4	41.0	18.9	30.4	0.82	1.89	1.76	1.49
RCH	0	HW	.[w]	54.9	40.9	47.9	2.04	1.25	2.73	2.01
		LW	.	44.3	36.4	40.4	2.83	2.96	2.06	2.62
	1.8	HW	.	41.9	32.7	37.3	1.04	1.45	2.00	1.50
		LW	.	47.3	30.2	38.8	2.80	2.11	1.73	2.21
	4.5	HW	.	49.4	33.2	41.3	1.49	1.80	2.97	2.09
		LW	.	47.7	36.7	42.2	2.18	2.47	2.73	2.46

[z]ANOVA indicated weeds affected percentage fruit set at CVR (P=0.014).

[y]Effect of weeds on number of terminal buds varied with year at RCH (P=0.015). Significant differences occurred in 1999 (P=0.005) and 2000 (P=0.014). Effect of herbicide on terminal buds varied by year at CVR (P=0.001). Significant differences occurred in 2000 (P=0.006) and 2001 (P=0.002).

[x]Bi-annual vine sampling began in 1999.

[w]RCH fall vines samples collected after fruit was removed during commercial harvest. Data not available.

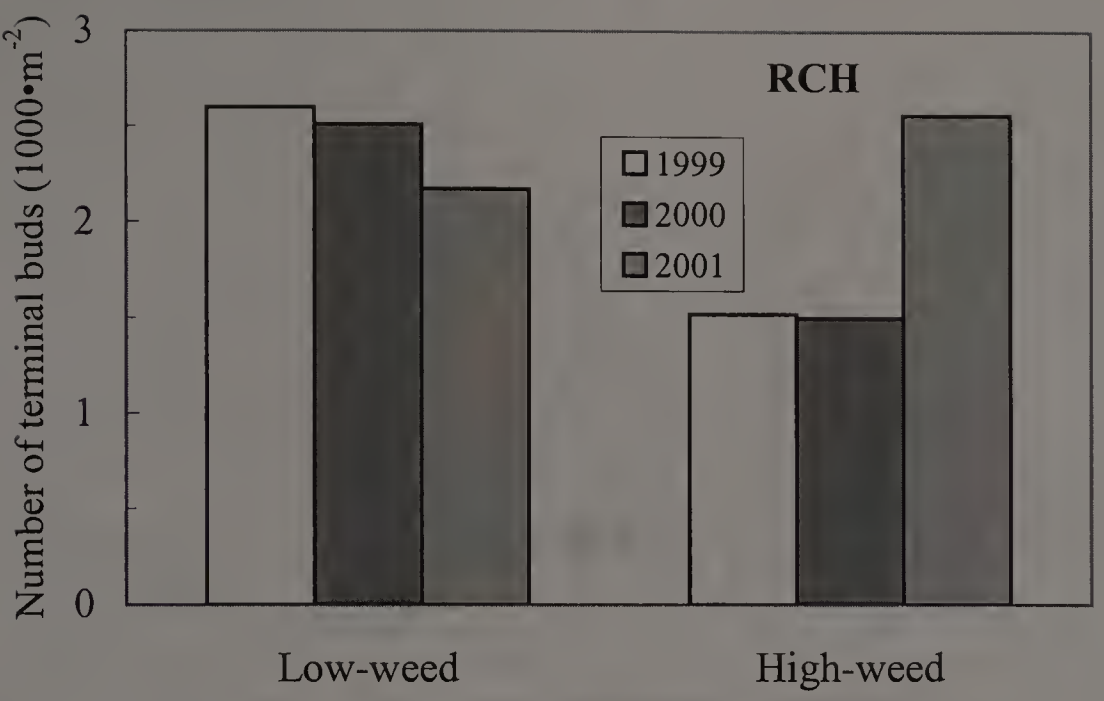

Figure 2.6. Interaction of weediness and year on the number of terminal buds on uprights collected from plots (RCH) treated with various rates of dichlobenil (N=12). Significant differences occurred between HW and LW in 1999 and 2000.

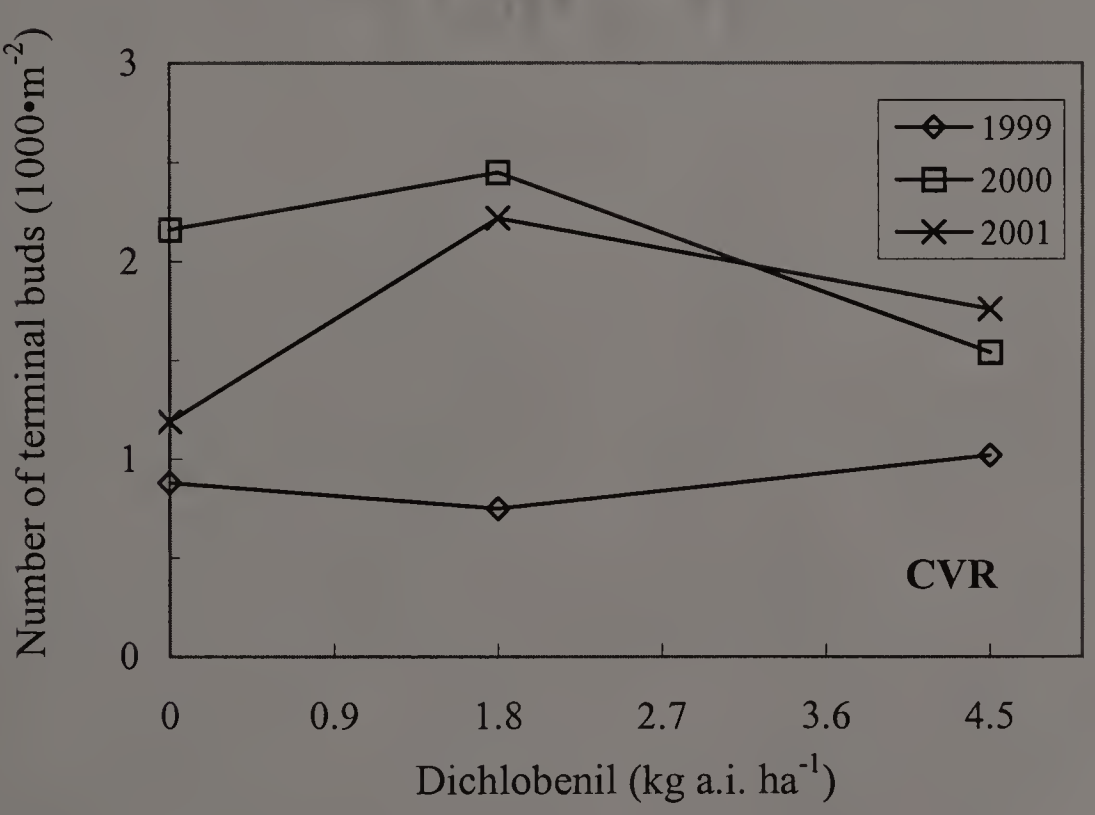

Figure 2.7. Fall sampling. Interaction of herbicide and year on number of terminal buds on uprights collected from plots (CVR) treated with various rates of dichlobenil (N=8). Herbicide rate affected number of terminal buds in 2000 and 2001.

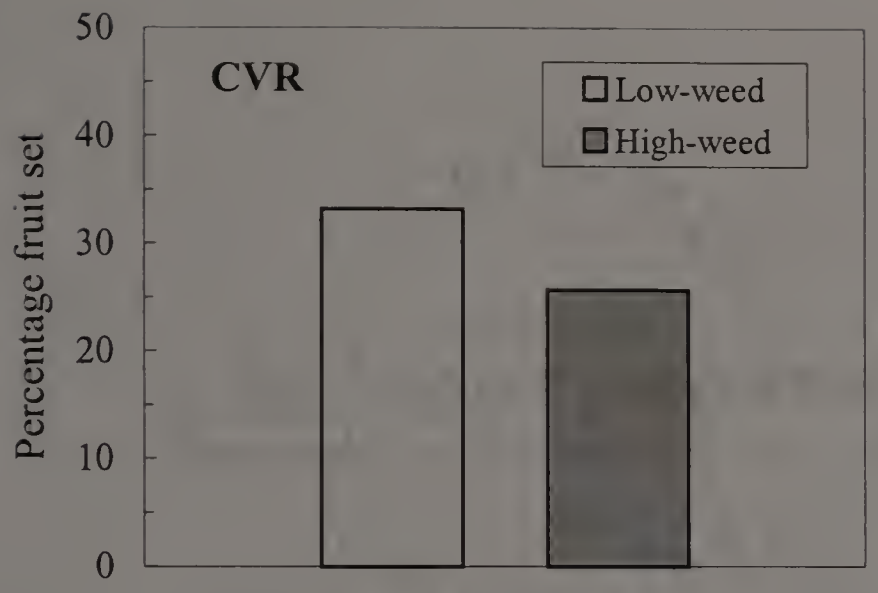

Figure 2.8. Effect of weed presence on the percentage of fruit set in plots (CVR) treated with various rates of dichlobenil for four years (N=48).

Table 2.10. Healthy berry weights produced in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	Weight per berry (g)[z]				
		1998	1999	2000	2001	Mean
0	HW	1.02	1.05	0.92	1.02	1.00
	LW	1.06	1.04	0.92	1.02	1.01
1.8	HW	1.11	1.04	0.91	1.03	1.02
	LW	1.07	1.06	0.94	1.02	1.02
4.5	HW	1.10	1.06	0.93	1.03	1.03
	LW	1.07	1.02	0.90	1.08	1.02

[z]ANOVA indicated no significant treatment effects.

Table 2.11. Yield parameters in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=8).

Rate	Weed	Yield (Mg•ha^{-1})[z]									
		Total					Marketable				
(kg a.i. ha^{-1})	status	1998	1999	2000	2001	Mean	1998	1999	2000	2001	Mean
0	HW	15.2	13.7	18.6	10.6	14.5	14.3	13.2	14.2	8.7	12.6
	LW	25.2	19.5	26.5	18.0	22.3	23.7	19.1	21.5	13.7	19.5
1.8	HW	14.7	16.6	20.3	12.4	16.0	13.7	16.9	16.2	10.0	14.2
	LW	21.1	20.5	25.1	17.8	21.1	19.8	21.1	19.6	12.7	18.3
4.5	HW	15.4	15.5	17.0	9.5	14.4	13.6	15.2	14.0	7.8	12.7
	LW	21.4	18.6	27.5	17.4	21.2	21.3	17.4	21.3	14.4	18.6

[z]ANOVA indicated weeds affected total yield ($P<0.001$) and marketable fruit ($P<0.001$).

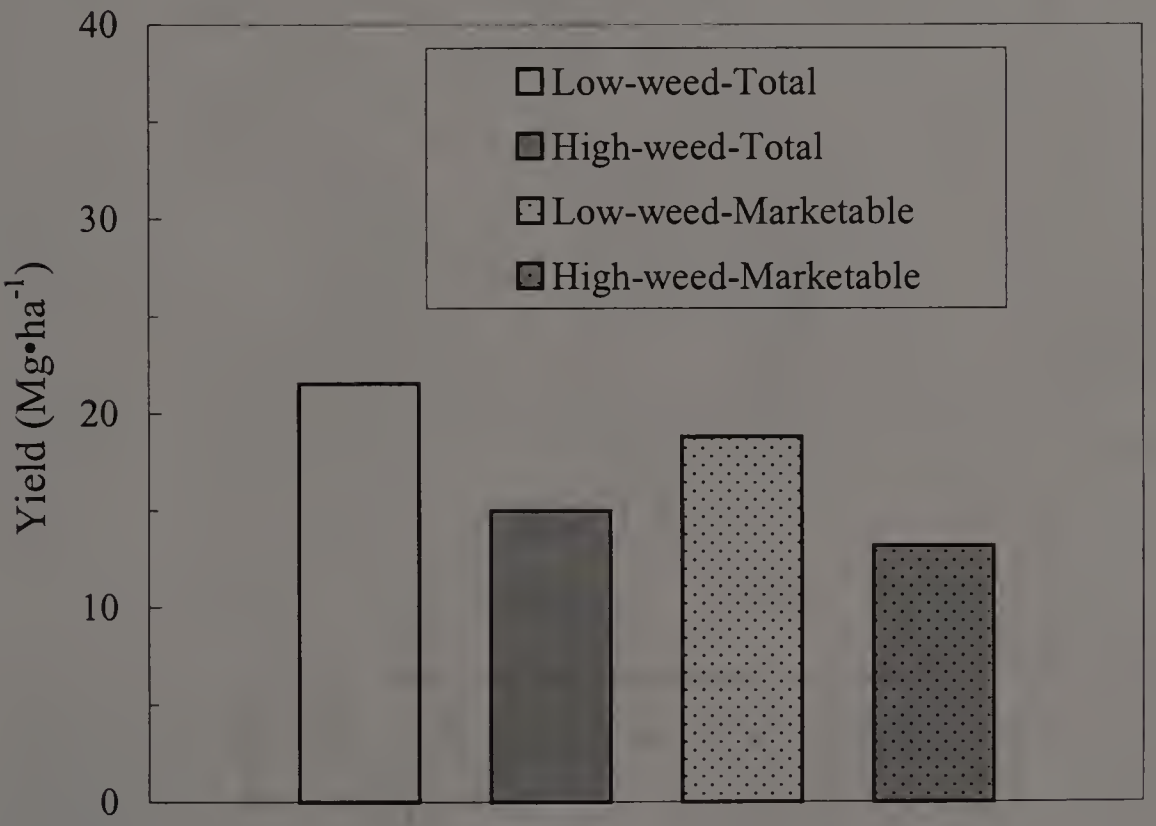

Figure 2.9. Effect of weed presence on total and marketable yield collected from plots treated with various rates of dichlobenil for four years (N=96).

Table 2.12. Percentage unusable yield collected from high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

Site	Rate (kg a.i. ha^{-1})	Weed status	Unusable yield (%)[z] 1998	1999	2000	2001	Mean
CVR	0	HW	8.9	17.2	22.2	42.5	22.7
		LW	5.4	5.5	9.7	26.6	11.8
	1.8	HW	10.6	8.9	20.5	43.8	21.0
		LW	7.2	6.6	15.4	31.8	15.3
	4.5	HW	13.8	16.8	18.2	54.7	25.9
		LW	8.9	4.6	14.3	44.8	18.2
RCH	0	HW	13.0	12.3	10.0	16.0	12.8
		LW	10.6	8.9	14.0	27.1	15.2
	1.8	HW	10.4	7.7	7.5	16.9	10.6
		LW	14.3	2.9	13.8	30.4	15.4
	4.5	HW	11.1	10.1	9.0	18.8	12.3
		LW	6.2	10.0	7.0	15.7	9.7

[z]ANOVA indicated weeds affected percentage unusable yield at CVR (P=0.010).

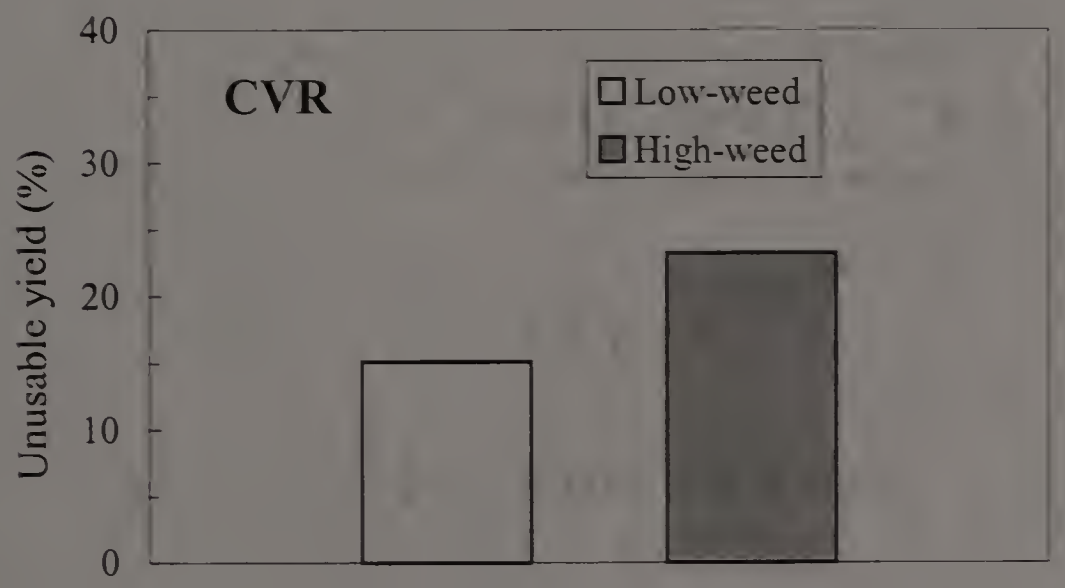

Figure 2.10. Effect of weed presence on % unusable fruit from plots (CVR) treated with various rates of dichlobenil for four years (N=48).

Table 2.13. Cranberry root length in high-weed (HW) and low-weed (LW) plots treated with various rates of dithiobenzil (N=5).

Rate (kg a.i. ha^{-1})	Weed status	Cranberry root length (mm)[a]			
		June 00	Sep. 00	Aug. 01	Mean
0	HW	66.2	62.8	43.6	57.5
	LW	72.6	58.8	60.1	63.8
1.8	HW	68.4	63.3	45.6	59.1
	LW	62.9	66.1	53.0	60.7
4.5	HW	58.6	53.9	41.3	51.3
	LW	61.9	73.4	50.4	61.9

[a]The interaction of weeds and herbicide varied by date (P=0.011). Effects were seen at the high rate Sep. 00 (P=0.004) and at the untreated in Aug. 01 (P=0.012).

Table 2.14. Integer cover class values assigned to percentage cover ranges used in vegetation survey.

Percentage cover range	Cover class values
0	0
<1	1
1-5	2
6-10	3
11-25	4
26-40	5
41-60	6
61-75	7
76-90	8
>90	9

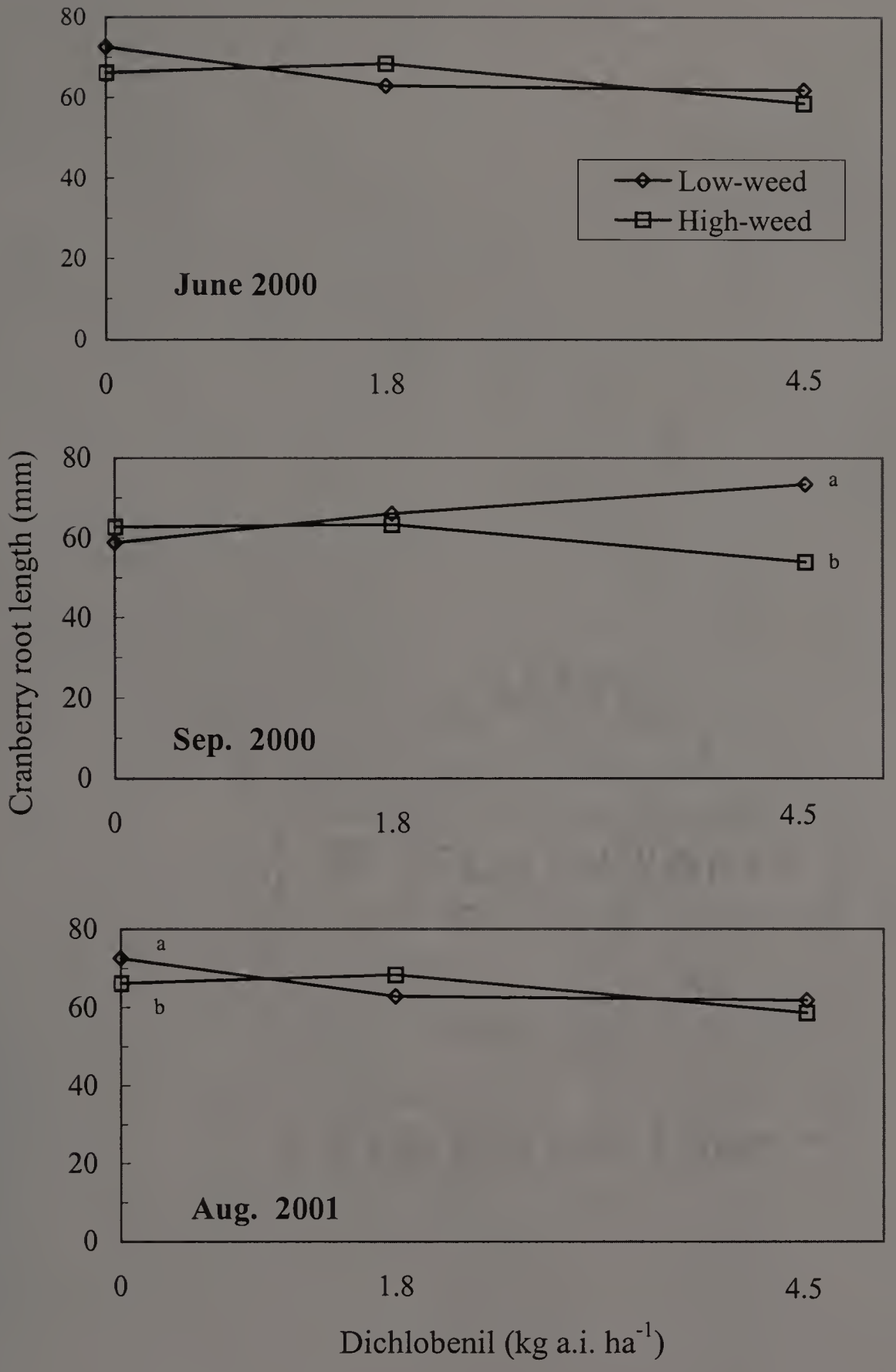

Figure 2.11. Interaction of weediness and herbicide applications with date of sampling on cranberry root length (N=8). Means with similar letters are not significantly different according to Kramer-adjusted Tukey HSD (P=0.05).

Table 2.15. List of plant species identified at Carver. Percentage frequency and maximum cover class values (CCV) are listed for each species for each year of the study.

Species name	Common name	Frequency (%)[z] 1998	1999	2000	2001
Acer rubrum	red maple	8.3	20.8	16.7	37.5
Apios americana	wild bean	29.2	37.5	45.8	50.0
Asclepias syriaca	milkweed	nd	nd	4.2	nd
Aster sp.	asters	12.5	4.2	4.2	nd
Carex longeii		nd	8.3	nd	nd
Cuscuta gronovii	swamp dodder	4.2	4.2	nd	nd
Cyperus dentatus	nut sedge	nd	nd	4.2	nd
Epilobium angustifolium	fireweed	nd	8.3	nd	nd
Eupatorium dubium	Joe-pye weed	4.2	nd	nd	4.2
Euthamia tenuifolia	narrow-leaved goldenrod	41.7	58.3	50.0	50.0
Glyceria canadensis	rattlesnake grass	nd	4.2	nd	nd
Leersia oryzoides	cut grass	nd	12.5	8.3	8.3
Lysimachia terrestris	yellow loosestrife	nd	12.5	8.3	16.7
Muhlenbergia capallaris	smokegrass	nd	4.2	8.3	nd
Panicum sp.		nd	nd	nd	4.2
Polygonum sagittatum	arrow-leaved tearthumb	nd	4.2	nd	nd
Pyrus melanocarpa	chokeberry	nd	4.2	4.2	nd
Rubus allegheniensis	upright bramble	4.2	nd	nd	4.2
Rubus hispidus	bristly dewberry	8.3	8.3	nd	8.3
Spirea alba	meadowsweet	4.2	4.2	nd	4.2
Vaccinium macrocarpon	American cranberry	100.0	100.0	100.0	100.0
Viburnum recognitum	north arrow-wood	nd	4.2	nd	nd
Viola lanceolata	white violet	8.3	45.8	45.8	33.3

continued, next page

Table 2.15, continued

Species name	Common name	Max CCV[z] 1998	1999	2000	2001
Acer rubrum	red maple	2	2	2	2
Apios americana	wild bean	5	7	9	6
Asclepias syriaca	milkweed	nd	nd	2	nd
Aster sp.	asters	4	1	2	nd
Carex longeii		nd	2	nd	nd
Cuscuta gronovii	swamp dodder	1	1	nd	nd
Cyperus dentatus	nut sedge	nd	nd	1	nd
Epilobium angustifolium	fireweed	nd	2	nd	nd
Eupatorium dubium	Joe-pye weed	1	nd	nd	2
Euthamia tenuifolia	narrow-leaved goldenrod	4	5	3	5
Glyceria canadensis	rattlesnake grass	nd	2	nd	nd
Leersia oryzoides	cut grass	nd	1	2	3
Lysimachia terrestris	yellow loosestrife	nd	2	3	nd
Muhlenbergia capallaris	smokegrass	nd	2	2	nd
Panicum sp.		nd	nd	nd	3
Polygonum sagittatum	arrow-leaved tearthumb	nd	1	nd	nd
Pyrus melanocarpa	chokeberry	nd	2	2	nd
Rubus allegheniensis	upright bramble	2	nd	nd	4
Rubus hispidus	bristly dewberry	3	2	nd	3
Spirea alba	meadowsweet	2	1	nd	3
Vaccinium macrocarpon	American cranberry	9	9	9	9
Viburnum recognitum	north arrow-wood	nd	2	nd	nd
Viola lanceolata	white violet	2	3	2	3

[z]nd = not detected.

Table 2.16. List of plant species identified at Rochester. Percentage frequency and maximum cover class values (CCV) are listed for each species for each year of the study.

		Frequency (%)[z]			
Species name	Common name	1998	1999	2000	2001
Acer rubrum	red maple	12.5	54.2	37.5	41.7
Aster spp.	asters	nd	8.3	4.2	nd
Cyperus dentatus	nut sedge	4.2	16.7	16.7	20.8
Epilobium angustifolium	fireweed	nd	nd	nd	4.2
Euthamia tenuifolia	narrow-leaved goldenrod	95.8	95.8	95.8	100.0
Leersia oryzoides	cut grass	16.7	29.2	33.3	29.2
Lysimachia terrestris	yellow loosestrife	4.2	nd	8.3	nd
Panicum spp.		4.2	4.2	nd	4.2
Rubus hispidus	bristly dewberry	12.5	25.0	20.8	20.8
Salix spp.	willow	nd	4.2	12.5	4.2
Spirea alba	meadowsweet	nd	4.2	nd	nd
Toxicodendron radicans	poison ivy	4.2	4.2	8.3	8.3
Vaccinium macrocarpon	American cranberry	100.0	100.0	100.0	100.0
Viola lanceolata	white violet	50.0	91.7	79.2	66.7

		Max CCV[z]			
Species name	Common name	1998	1999	2000	2001
Acer rubrum	red maple	2	2	2	2
Aster spp.	asters	nd	1	1	nd
Cyperus dentatus	nut sedge	2	2	4	4
Epilobium angustifolium	fireweed	nd	nd	nd	2
Euthamia tenuifolia	narrow-leaved goldenrod	4	6	6	7
Leersia oryzoides	cut grass	2	4	6	6
Lysimachia terrestris	yellow loosestrife	1	nd	1	nd
Panicum spp.		2	6	nd	4
Rubus hispidus	bristly dewberry	4	4	4	4
Salix spp.	willow	nd	1	1	2
Spirea alba	meadowsweet	nd	1	nd	nd
Toxicodendron radicans	poison ivy	3	2	1	2
Vaccinium macrocarpon	American cranberry	9	9	9	9
Viola lanceolata	white violet	3	4	2	3

[z]nd=not detected.

Table 2.17. Percentage cover for weed species at Carver (CVR), sorted by high-weed and low-weed locations.

CVR - High-weed

	Cover (%)[z]			
Genus species	1998	1999	2000	2001
Acer rubrum	7.4	6.5	nd	7.4
Apios americana	0.3	2.7	20.1	24.8
Aster sp.	4.2	nd	nd	nd
Carex longeii	nd	7.4	nd	nd
Cuscuta gronovii	8.3	8.3	nd	nd
Cyperus dentatus	nd	nd	8.3	nd
Epilobium angustifolium	nd	6.5	nd	nd
Eupatorium dubium	8.3	nd	nd	nd
Euthamia tenuifolia	0.4	3.7	0.5	4.2
Glyceria canadensis	nd	7.4	nd	nd
Leersia oryzoides	nd	6.5	6.5	4.9
Lysimachia terrestris	nd	4.2	6.5	5.7
Panicum sp.	nd	nd	nd	6.5
Polygonum sagittatum	nd	8.3	nd	nd
Pyrus melanocarpa	nd	7.4	7.4	nd
Rubus allegheniensis	7.4	nd	nd	5.7
Rubus hispidus	4.9	5.7	nd	5.7
Spirea alba	nd	8.3	nd	6.5
Viola lanceolata	nd	4.2	3.0	2.0

CVR - Low-weed

	Cover (%)[z]			
Genus species	1998	1999	2000	2001
Acer rubrum	7.4	5.7	3.0	0.5
Asclepias syriaca	nd	nd	7.4	nd
Aster sp.	7.4	8.3	7.4	nd
Eupatorium dubium	nd	nd	nd	7.4
Euthamia tenuifolia	4.2	4.9	5.7	5.7
Lysimachia terrestris	nd	nd	7.4	6.5
Muhlenbergia capallaris	nd	7.4	7.4	nd
Spirea alba	7.4	nd	nd	nd
Viburnum recognitum	nd	7.4	nd	nd
Viola lanceolata	5.7	1.2	1.2	2.5

[z]nd=not detected.

Table 2.18. Percentage cover for weed species at Rochester (RCH), sorted by high-weed and low-weed locations.

RCH - High-weed

Genus species	Cover (%)[z] 1998	1999	2000	2001
Acer rubrum	7.4	4.2	3.6	5.7
Aster sp.	nd	8.3	8.3	nd
Cyperus dentatus	7.4	3.6	3.0	2.5
Epilobium angustifolium	nd	nd	nd	9.1
Euthamia tenuifolia	13.7	22.4	17.9	37.8
Leersia oryzoides	3.6	0.3	1.5	1.2
Lysimachia terrestris	8.3	nd	nd	nd
Panicum sp.	7.4	4.2	nd	5.7
Rubus hispidus	3.0	0.5	1.6	2.0
Salix sp.	nd	nd	nd	7.4
Toxicodendron radicans	6.5	nd	nd	nd
Viola lanceolata	3.6	0.7	1.0	1.0

RCH - Low-weed

Genus species	Cover (%)[z] 1998	1999	2000	2001
Acer rubrum	5.7	1.6	2.5	0.5
Aster sp.	nd	8.3	nd	nd
Cyperus dentatus	nd	nd	nd	8.3
Euthamia tenuifolia	3.7	6.9	7.6	12.8
Leersia oryzoides	nd	8.3	8.3	nd
Lysimachia terrestris	nd	nd	7.4	nd
Rubus hispidus	nd	7.4	7.4	7.4
Salix sp.	nd	8.3	6.5	nd
Spirea alba	nd	8.3	nd	nd
Toxicodendron radicans	nd	7.4	7.4	6.5
Viola lanceolata	0.3	2.2	0.3	0.3

[z]nd=not detected.

Table 2.19. Percentage cover for weed species in high-weed (HW) and low-weed (LW) plots treated with various rate of dichlobenil (N=8).

Rate (kg a.i. ha^{-1})	Weed status	Cover (%)[z]				
		1998	1999	2000	2001	Mean
0	HW	2.9	4.3	5.8	8.9	5.5
	LW	2.0	0.6	0.7	2.7	1.5
1.8	HW	3.8	3.2	15.0	10.5	8.1
	LW	0.9	0.5	1.1	1.8	1.1
4.5	HW	6.3	4.1	6.0	14.5	7.7
	LW	0.3	0.3	0.4	0.5	0.4

[z]ANOVA indicated weediness affected percentage cover ($P<0.001$).

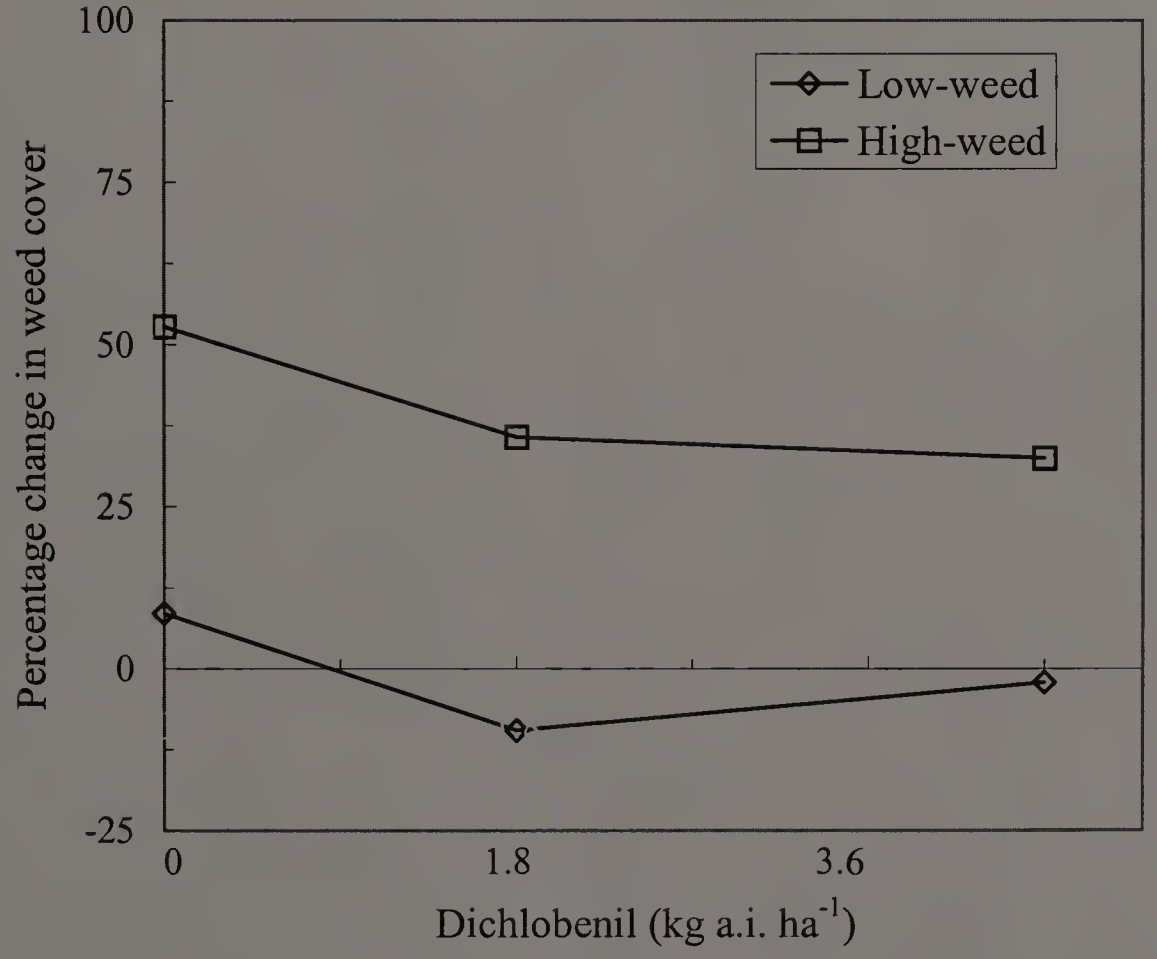

Figure 2.12. Effect of weediness on percentage change of weed cover from 1998 to 2001 in plots treated with various rates of dichlobenil (N=8).

Table 2.20. Species richness in high-weed (HW) and low-weed (LW) plots (N=8).

Rate (kg a.i. ha^{-1})	Weed status	No. species per m^{2z}				
		1998	1999	2000	2001	Mean
0	HW	2.25	3.88	3.38	3.62	3.28
	LW	1.62	2.50	2.50	2.62	2.31
1.8	HW	2.12	3.88	2.38	3.12	2.88
	LW	1.12	2.25	2.88	2.00	2.06
4.5	HW	2.12	3.38	2.88	2.75	2.78
	LW	1.12	1.88	1.38	1.50	1.47

[z]ANOVA indicated both weeds and herbicide affected species richness (P=0.002 and P=0.049, respectively).

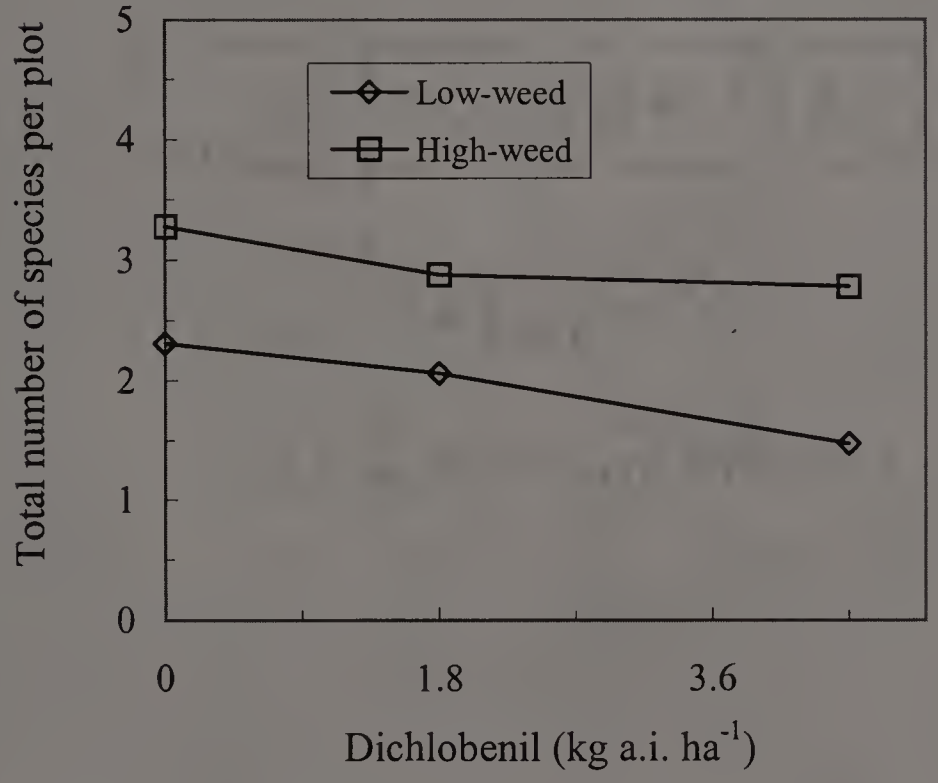

Figure 2.13. Effect of weediness and herbicide rate on species richness in plots treated with various rates of dichlobenil for four years (N=32).

Table 2.21. Shannon's diversity index in high-weed (HW) and low-weed (LW) plots treated with various rates of dichlobenil (N=4).

Site	Rate (kg a.i. ha^{-1})	Weed status	Shannon's diversity index[z] 1998	1999	2000	2001	Mean
CVR	0	HW	0.50	1.14	0.81	1.17	0.91
		LW	0.27	0.69	0.61	0.78	0.59
	1.8	HW	0.54	1.18	0.51	0.95	0.80
		LW	0.00	0.32	0.54	0.16	0.25
	4.5	HW	0.50	1.13	1.01	0.93	0.89
		LW	0.00	0.17	0.00	0.00	0.04
RCH	0	HW	0.73	1.29	1.37	1.17	1.14
		LW	0.51	0.91	0.97	0.96	0.84
	1.8	HW	0.58	1.23	0.86	1.08	0.94
		LW	0.50	1.11	1.21	0.94	0.94
	4.5	HW	0.74	1.03	0.87	0.82	0.87
		LW	0.62	1.04	0.80	0.85	0.83

[z]ANOVA indicated weeds affected Shannon's diversity index at CVR (P= 0.012).

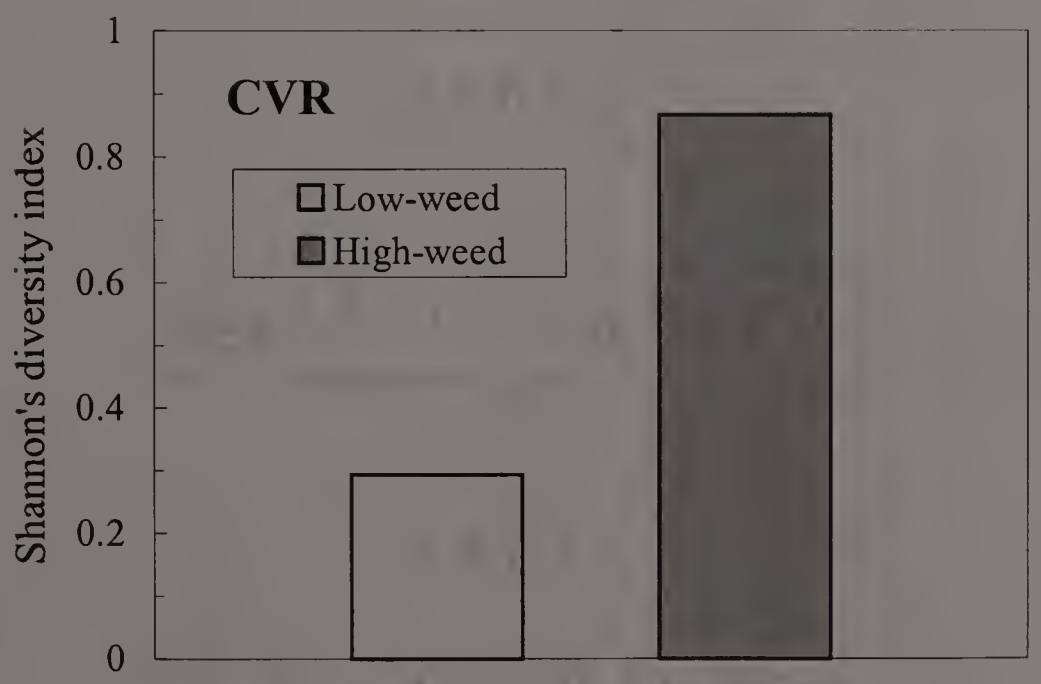

Figure 2.14. Effect of weediness on Shannon's diversity index in plots (CVR) treated with various rates of dichlobenil for four years (N=48).

Table 2.22. Root length of alfalfa seedlings incubated on soil collected from plots treated with various rates of dichlobenil (N=8).

Rate	Date	Weed	Alfalfa root length (mm)[z]					
			1998					
(kg a.i. ha^{-1})	applied	status	May 4	May 21	June 3	June 25	July 15	Aug.[y]
0		HW	10.2	3.8	24.5	15.1	16.7	20.5
		LW	19.3	3.7	22.8	14.8	15.2	20.4
1.8	Apr. 29	HW	n/d	2.1	16.8	13.4	13.5	17.5
		LW	n/d	4.4	19.5	11.3	17.3	21.7
4.5	Apr. 12	HW	4.6	2.7	12.3	5.5	12.3	17.2
		LW	4.1	2.4	12.8	9.7	13.4	19.1
Rate	Date	Weed	1999					
(kg a.i. ha^{-1})	applied	status	May 7	May 24	June 15	July 6	July 27	
0		HW	14.0	11.8	9.9	24.6	13.9	
		LW	19.2	13.5	7.7	23.6	14.8	
1.8	May 3	HW	n/d	10.0	6.1	22.8	13.8	
		LW	n/d	7.4	6.4	21.5	13.7	
4.5	Apr. 19	HW	4.5	6.0	8.0	20.1	14.1	
		LW	3.2	3.9	3.3	20.3	13.0	
Rate	Date	Weed	2000					
(kg a.i. ha^{-1})	applied	status	Mar. 30	May 8	May 30	June 19	July 10	Aug. 8[y]
0		HW	25.8	23.2	19.0	22.4	18.9	18.0
		LW	28.1	24.6	19.4	28.0	19.9	18.2
1.8	May 15	HW	33.6	23.7	15.9	21.1	18.7	23.1
		LW	33.2	24.2	15.7	21.2	22.6	18.8
4.5	Apr. 7	HW	33.3	17.9	16.8	20.9	15.7	14.7
		LW	35.8	16.4	16.7	17.6	16.6	11.2
Rate	Date	Weed	2001					
(kg a.i. ha^{-1})	applied	status	Apr. 16	May 16	June 6	June 28	July 18	Aug[y]
0		HW	25.4	18.8	22.8	19.6	18.8	22.7
		LW	20.5	21.3	23.2	22	20	24.9
1.8	May 3	HW	21.1	n/d	21.2	17.2	17.1	21.2
		LW	23.4	n/d	21.4	15.1	14.9	23.6
4.5	Apr. 19	HW	21.6	9.1	17.6	21.4	16.4	17.8
		LW	22.5	8.5	14.9	15.0	15.3	21.1

[z]ANOVA indicated the effect of herbicide on root length varied by year (P=0.020).

[y]1998: Aug. 5 (CVR), Aug. 25 (RCH); 2000: CVR only (N=4); 2001: Aug. 8 (CVR), Aug. 16 (RCH).

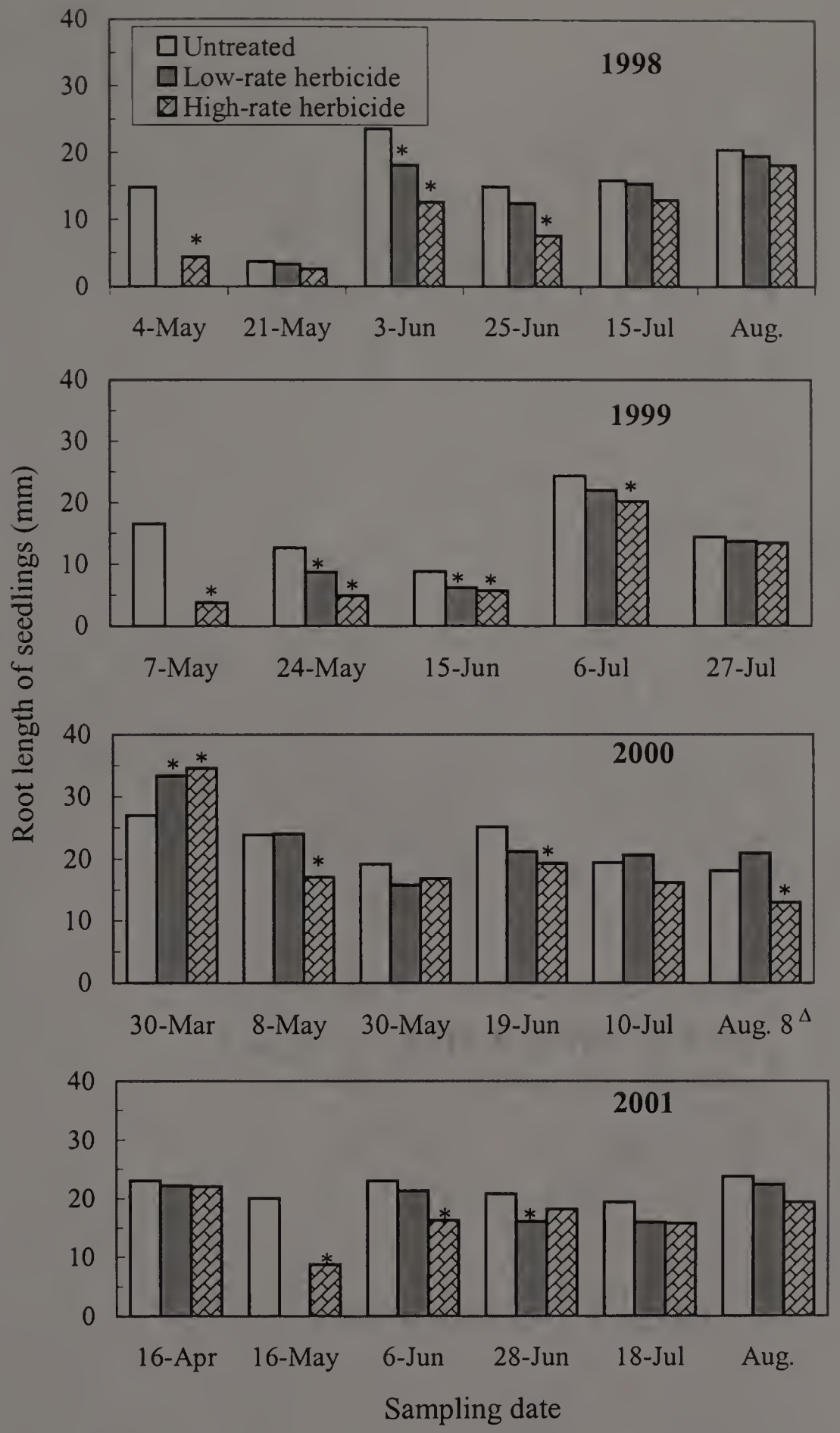

Figure 2.15. Interaction of herbicide rate and year on root length of alfalfa seedlings incubated on soil collected from plots treated with various rates of dichlobenil (N=16). Within each date and year, bars with asterisks are significantly different from the untreated according to Dunnett's test (P=0.05).

ΔBars reflect samples from CVR only for this date.

CHAPTER 3

EVALUATION OF WEED MANAGEMENT OPTIONS, NITROGEN RATE, AND VINE DENSITY ON CRANBERRY AND WEED BIOMASS

Introduction

Over 70 species of plants have been classified as weeds commonly found on commercial cranberry bogs (Demoranville, 1984; Demoranville, 1986; Sears et al., 1996). Approximately 48% of the species are broad-leaved plants, 25% are grass species, 14% are sedges, 7% are aquatic plants, 5% species are rushes, and 1% parasitic plants. Many of these species have been identified as serious pests (Crop Profile, 2002) and can cause significant losses in cranberry production (Devlin and Deubert, 1980; Else et al., 1992; Mahr and Moffitt, 1994; Patten and Wang, 1994). On established plantings, weed losses may vary based on the composition (type) of species present, their ability to spread and cause yield loss, and available control techniques (Else et al., 1995). Though growers may decide to scrape and renovate their production areas for other reasons (e.g., lack of even grade across the production surface), severe weed infestations frequently necessitate the use of this drastic option (DeMoranville et al., 2001; Sandler, 2003). Since the early 1990s, growers have also opted to build new cranberry beds in nontraditional upland areas (Gilmore, 1992; DeMoranville et al., 1996). Grower experience has certainly indicated that managing weed species in new plantings (either upland or renovated traditional production areas) is essential for minimizing costs and promoting quick coverage of the bog surface by vines. Failing to manage weeds initially leads to higher labor and monetary inputs over the productive life of the bog.

Previous research has verified grower experience and demonstrated that weeds impact the establishment, growth, and/or fecundity of cranberry vines (Hicks et al., 1968; Mahr and Moffitt, 1994; Patten and Wang, 1994) as well as yield and fruit quality (Patten and Wang, 1994).

Information on fertilizer use, weed management, and choice of vine material (that would aid in management decisions) is available for each practice individually, but has not been evaluated in a combined forum. The impact of weed colonization during cranberry vine establishment (in terms of production of crop/weed biomass and crop yield) has not been quantified. The dynamics of vine establishment, crop performance, and weed growth in the early years of a newly planted cranberry bed have not been documented in the literature and is mostly observational.

Improved crop performance with weed control (minimizing losses due to weed infestation) has been documented on other newly planted perennial fruit crops. Initial and continued weed control were important in maintaining acceptable tree growth (measured as increases in trunk circumference) for several crop species as newly planted orchard trees (Mellenthin et al., 1966). The temporal component of weed management (i.e., varying periods of minimal weed competition during establishment) substantially influenced tree growth, fruit production, and yield efficiency in apple (*Malus x sylvestris* (L.) Mill. var. *domestica*) (Merwin and Ray, 1997) and tart cherry (*Prunus cerasus* L.) (Al-Hinai and Roper, 2001). A 6-yr study on newly planted apple trees showed that different systems of groundcover management had variable implications in terms of tree establishment, overall leaf nutrition, and yield (Merwin and Stiles, 1994).

Weeds may impact crop plants directly by competing for water, light, and nutrients (Patterson, 1995; Radosevich et al., 1997). Without weed control, no combination of irrigation, fertilization, or pruning produced acceptable 'Niagara' grapevine (*Vitis vinifera* L.) size (Zabadal and Dittmer, 2001). Weeds may vary in their ability to compete with crops. Orchardgrass (*Dactylis glomerata* L.) reduced vegetative growth and yield in mature peach (*Prunus persica* (L.) Batsch.) trees more than perennial ryegrass (*Lolium perenne* L.) and other grass species (Tworkoski and Glenn, 2001). Patten and Wang (1994) showed that the relationship between light absorbed by the weed canopy and weed biomass varied by weed species for West Coast

cranberry beds. Weed populations reduced cranberry yield linearly, and the authors speculated that competition for light was likely the limiting factor.

Weeds may also cause indirect effects in cranberry systems by competing for pollinators (Marucci and Moulter, 1977), serving as alternate hosts or habitats for cranberry pests (Averill and Sylvia, 1998), or hindering cranberry harvest operations (DeMoranville et al., 1996). Though not typically believed to be a common phenomenon (Zimdahl, 1999), competition with pollinators has also been documented in apple (Free, 1968). Young growing tips of yellow loosestrife (*Lysmachia terrestris* (L.) B.S.P.) may harbor larvae of Sparganothis fruitworm (*Sparganothis sulfureana* Clemens), a serious direct pest of cranberry. Cranberry weevil (*Anthonomus musculus* Say) uses many weed species commonly found on cranberry farms as alternative food sources (Mechaber and Chew, 1991). On the other hand, herbaceous plants have been evaluated as to their attractiveness to bumble bees (*Bombus* sp.) and honey bees (*Apis mellifera* L.) to promote pollination on cranberry farms (Patten et al., 1993). Other cranberry insects, such as black vine weevil (*Otiorhynchus sulcatus* F.), strawberry root weevil (*O. ovatus* L.), and cranberry white grub (*Phyllophaga anxia* LeConte), have been observed feeding on weeds in cranberry bogs (Averill and Sylvia, 1998). The role of these plants in the dynamics of new or established cranberry systems (beneficial or detrimental) is not known.

The importance of nitrogen in maintaining commercial crop productivity is well recognized (Barker and Mills, 1980). Many studies have shown, however, that abundant nitrogen may favor weed species over the crop plants. Consequently, manipulation of nitrogen rates in various agricultural systems has been pursued as an area for potential weed management. Published research results on the interaction of nitrogen and weed populations with either herbicide application or cultural methods vary widely. Even though weed biomass was often lowest in plots that received the highest amount of fertilizer, no consistent relationship of nitrogen on total weed biomass was seen in three different crop rotations (crop species included winter wheat [*Triticum aestivum* L.], turnip rape [*Brassica rapa* L.], and oats [*Avena sativa* L.]), each

with four rates of nitrogen (Andersson and Milberg, 1996). A recent study comparing cultural and herbicide methods and fertilizer on crop yield of fall rye (*Secale cereale* L.), spring wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.) showed significant increases in the occurrence of green foxtail (*Setaria viridis* (L.) P. Beauv.) and improved straw and grain yields in fertilized plots compared to unfertilized plots (Stevenson et al., 2000). Several weed species were more prevalent in plots with cultural controls than herbicide-treated plots, and crop yield was unaffected by weed control method. Simple techniques such as proper placement and timing of fertilizers (especially in annual crops) can favor crop competitiveness and minimize negative weed impacts (Di Tomaso, 1995).

For many research experiments, cultural methods and herbicides will often interact to influence results. In an effort to identify cultural methods that would minimize weed development in tall fescue (*Festuca arundinacea* Schreb. cv. Rebel II), researchers reported that the effect of mowing height on tall fescue quality and the encroachment of smooth crabgrass (*Digitaria ischaemum* (Schreber) Muhl.) and white clover (*Trifolium repens* L.) varied with herbicide application (Dernoeden et al., 1993). A different integrated weed management program was recommended depending on choice of mowing height. Management plans integrating alley sward width, irrigation, and nitrogen were examined in newly planted apple trees (Hipps et al., 1990). After four years, greater girths were measured in trees receiving irrigation and trees in uncultivated soil maintained bare with herbicide than trees growing in narrow and wide bare soil strips between grassed alleys. This general trend persisted throughout the life of the orchard. Sometimes, it is difficult to discern strong trends among cultural practices, fertilizer, and weed populations. A 9-year study evaluating the effects of tillage system, cover crop, and nitrogen gave inconsistent results regarding weed density and tillage system (Swanton et al., 1999). The authors suggested that factors such as tillage, environment, and weed management may play a larger role in determining weed flora than nitrogen.

Various planting schemes are available for the production of perennial fruit. For example, vigorous rootstocks, dwarfing rootstocks, and/or high-density plantings have been used to achieve better yields with easier fruit tree maintenance (Schneider et al., 1978; Layne et al., 1981; Layne and Tan, 1984; Testolin, 1990). Challenges remain even when using these alternative plantings. Lack of weed suppression in the early years of an orchard reduced the long-term growth of apple trees, in spite of increased nitrogen application (White and Holloway, 1967). Establishment of perennial fruit plants may be hindered by herbicide use (Devlin and Demoranville, 1968b; Yarborough and Bhowmik, 1989; Hogue and Peters, 1994). Nitrogen application is important for the establishment of many perennial fruit crops, but specific quantitative data especially for alternate density plantings are lacking. Recent studies on high bush blueberry (*Vaccinium corymbosum* L.) provided baseline nitrogen data for high-density (10,000 plants per ha) plantings (Reeder et al., 1994; Obreza et al., 1997). The effect of nitrogen application on trunk cross-sectional area varied with irrigation technique in high-density peach (*Prunus persica* (L.) Batsch.) orchards, but irrigation and fertilizer application had no effect on yield over a 4-yr period (Layne et al., 1996).

Each with a different slant, a few studies are available that have investigated the interaction of crop establishment and crop density, nitrogen application, and weed management. Especially when targeting the development of pest management practices, these investigations can be quite complex and may be difficult to extrapolate to other agricultural systems. Interactions with herbicides, nitrogen, and other pest problems that limit cotton (*Gossypium hirsutum* L.) production were studied over a 3-yr period (Gaylor et al., 1983). Generally, high rates of herbicide had the most unfavorable effects when yield potential was the highest (early planting, high nitrogen, and good insect control). Yield effects with variable nitrogen applications were inconsistent. Transplanted rice (*Oryza sativa* L.) yields were greatly increased when weed control treatments were associated with the application of nitrogen at rates between 28 and 84 $kg \cdot ha^{-1}$ (Kolhe et al., 1988). Herbicide applications were comparable to two hand-

weedings for maximizing yields and reducing weed biomass. In another study, nitrogen applied at 82 kg•ha^{-1} (+ two hand weedings) or 86 kg•ha^{-1} with herbicide treatment provided more efficient rice yields (Sharma et al., 1986) compared to nitrogen rates of 120 kg•ha^{-1} with no weed control.

The objectives of this study were to evaluate the interactions of nitrogen application, initial cranberry vine density, and weed management approach to define which combination(s) would promote successful cranberry vine colonization. In addition, the following questions were also of interest: Could herbicide or nitrogen inputs be reduced at higher vine densities? Did any nitrogen rate/vine density combination favor crop biomass production over weed biomass production? What weed management option was most effective in minimizing weed biomass?

Materials and Methods

General Project Description and History Outline 1999-2001

Approximately 0.2 ha of cranberry bog at the State Bog at the UMass Cranberry Station, East Wareham, MA was scraped and leveled in the fall of 1999. The fumigant, dazomet (tetrahydro-3,5-dimethyl-2H-1,3,5-thiodiazine-2-thione), was applied on 29 Oct. 1999 at 333 kg•ha^{-1} active ingredient (a.i.). The primary target spectrum for dazomet is weed seeds (Meister, 2002). A field trial was established in this renovated section in a fashion adapted from work presented by previous researchers (Burke and Grime, 1996). The following treatments were included in all combinations: 1) four nitrogen levels: 0, 28, 56, and 112 kg•ha^{-1}; 2) four vine densities: 0, 1.8, 3.6, and 5.4 metric tons (t) per hectare of the cultivar, Stevens; and 3) four weed treatments: natural recruitment (no weed control), inoculation with weed seeds, application of a preemergence herbicide, and postemergence control. Though not technically a measure of plant density (i.e., no. plants/unit area), the term "vine density" is commonly used in commercial

cranberry production to denote the amount of vine cuttings applied to an acre (DeMoranville et al., 2001; Strik, 2002). This common industry term is used throughout the manuscript. The experiment was replicated four times in a randomized-complete-block-split-split-plot design.

The cultivars, Early Black and Howes, are the two most common cranberry varieties grown in Massachusetts. The cultivar chosen for this study, Stevens, is a high-yielding, vigorous hybrid (McFarlin x Potter) that produces large berries (Eck, 1990). The cultivar is widely planted in Wisconsin and is gaining in popularity in the Massachusetts industry, especially for use in new plantings.

The preemergence and postemergence treatments are two possible weed management options that cranberry growers could use in a commercial setting. To ensure that sufficient weed pressure would be present in the study, one treatment included inoculation with several common cranberry weed seeds. Although not technically a management option, the deposition of materials (either sand or vines) containing weed seeds is a potential problem that growers might encounter in newly planted beds (Sandler et al., 2001). For the purposes of this study, these weed treatments were collectively designated as weed management options (WMO).

Each nitrogen plot (4 x 8 m) was subdivided into four density subplots (2 x 4 m each) and each density plot was subdivided into four weed WMO (1 x 2 m each). An untreated lane of approximately 0.3 m separated each WMO from its nearest neighbor. Each density plot was approximately 0.6 m away from the nearest density plot, and the largest plots were separated by at least 1 m. Replicates were separated by at least 3 m. 'Stevens' vines, obtained from local commercial cranberry growers, were spread by hand and disked in by a commercial planting machine on 4 May 2000. Vines were fertilized at planting with 112 $kg \cdot ha^{-1}$ triple superphosphate (0N-19.8P-0K), and irrigated as recommended for new cranberry plantings (DeMoranville et al., 2001). A coded map (Appendix B.1) is a schematic of the plot layout.

Nitrogen Treatments

In both 2000 and 2001, nitrogen was applied in five equal doses of 5.6, 11.2, and 22.4 $kg \cdot ha^{-1}$, alternately as urea (46N-0P-0K) or as a complete granular fertilizer proportioned as 19N-8.2P-15.8K. With the latter fertilizer, nitrogen was applied in the ammoniated form, as cranberries preferably take up nitrogen in this form (Addoms and Mounce, 1932; Greidanus et al., 1972; Rosen et al., 1990). Using a schedule where nitrogen sources were rotated, urea was applied on 30 May, 26 June, and 24 July 2000, and the NPK fertilizer was applied on 13 June and 11 July 2000. Similarly, urea was applied on 14 May, 14 June, and 12 July 2001, and the NPK fertilizer was applied on 29 May and 27 June 2001. Fertilizer was spread uniformly by hand across each nitrogen plot. Irrigation or rainfall typically followed application within 72 hr. During each of the initial two years of vine establishment, the total nitrogen applied to each plot was 0, 28, 56, or 112 $kg \cdot ha^{-1}$ (zero, low, medium, and high nitrogen, respectively). The plots designated to receive zero N did not receive any fertilizer inputs.

Vine Density and Weed Management Options

Each nitrogen plot was subdivided into four 2 x 4 m plots. Pre-weighed bags of cv. Stevens cranberry vines, equivalent to 0, 1.8, 3.6, and 5.4 $t \cdot ha^{-1}$, were scattered uniformly within each plot area. When all of the vines were scattered, a commercial planter traveled down each row and disked in the vines. Each vine density plot was subsequently subdivided into four 1 x 2 m experimental units. Invasion of grass and other weed species in newly planted cranberry beds are a significant concern, and current recommendations include application of a preemergence herbicide to minimize weed growth (DeMoranville et al., 2001). Thus, one group of subplots was treated annually with one preemergence application of napropamide (N,N-diethyl-2-(1-naphthalenyloxy)propanamide). We applied the active ingredient at 3.36 $kg \cdot ha^{-1}$ on 26 May 2000 (~ 3 wk after planting) and at 7.84 $kg \cdot ha^{-1}$ on 13 Apr. 2001. Each year, overhead irrigation was

used (approximately 2 hr) to incorporate the herbicide into the soil. Many of the target species listed on the label for napropamide are annual and perennial grasses, and few of the target broadleaved plants are present on cranberry bogs in Massachusetts (United Phosphorus, 2003). Thus, only emergent grass biomass was harvested from the Pre-WMO plots. Biomass was collected from randomly placed 900-cm^2 quadrats in each subplot on 22 June 2000 and 29 June 2001 and 2 July 2001.

Sometimes, growers may miss the opportunity to apply a preemergence herbicide in a new planting, or may opt not to use this management option. To evaluate the effectiveness of postemergence weed control, another subset of plots were treated with sethoxydim (2-{1-(ethoxyimino)butyl}-5-{2-(ethylthio)propyl}-3-hydroxy-2-cyclohexen-1-one) by backpack sprayer on 26 June 2000 and 2 July 2001. Sethoxydim is a selective postemergence grass herbicide. A 1.5% solution of the herbicide plus 1% by volume crop oil concentrate was applied at a pressure of 207 kPa. Many growers are willing to invest significant labor costs to hand-weed new plantings to manage early invaders. Consequently, the second part of the postemergence treatment included one hand-weeding event for each postemergence WMO plot (removing any living non-cranberry biomass, which was saved for subsequent evaluation) in late July through early August (25 July, 2 Aug., and 8 Aug. 2000; 21 July, 24 July, and 7 Aug. 2001). The time needed to remove the weeds was also recorded.

To ensure that sufficient weed pressure would be present in at least one of the WMO in the study, the third group of WMO plots was inoculated by sowing the seeds of four weed species into the designated areas. All species selected are considered to be problematic on new cranberry plantings (Demoranville, 1984; Demoranville, 1986; DeMoranville et al., 2001). Nut sedge (*Cyperus dentatus* Torr.), narrow-leaved goldenrod *(Euthamia tenuifolia* (Pursh) Nutt.), common flat-topped goldenrod (*E. graminifolia* (L.) Nutt.), and switchgrass (*Panicum virgatum* L.) seeds were distributed uniformly within each plot on 23 May 2000 (19 d after cranberry vine planting). Sowing density was based on seed size, as published by previous researchers (Burke and Grime,

1996). The grass seeds were sown at approximately 300 seeds•m^{-2}; all other seeds were sown at 550 seeds•m^{-2}. A fourth group of subplots received no treatment and served as an observation of natural recruitment as well as a reflection of no weed management efforts (untreated control).

Biomass Evaluations

As detailed below, both cranberry and weed biomass was collected at various times per annum. Biomass is known to be a valid indicator of energy allocation (Hickman and Pitelka, 1975) and was used to evaluate treatment effects.

Preemergence Weed Management Option

Grass plants from each nitrogen/density combination treated with the preemergence herbicide were collected from a randomly placed 900-cm^2 quadrat in late June of Year 1 and Year 2. The total number of grass plants for each sample was determined. Root systems were separated from their corresponding stems, and all tissue was dried in an oven at 60°C for at least 36 hr to determine stem and root dry biomass (pooled samples). Average stem length was determined by measuring 100 representative stems to the nearest millimeter and dividing the sum of these lengths by 100. If fewer than 100 stems were present in the sample, the sum of the stem lengths was divided by the number of stems present.

Postemergence Weed Management Option

During late July-early August of Year 1 and Year 2, living noncranberry plants were removed by hand from the 2-m^2 plots assigned to postemergence WMO. Emphasis was placed on removing plants as if the plots were being hand-weeded rather than being harvested for subsequent scientific scrutiny. However, preservation of the samples in a condition that would allow plant identification and biomass evaluation was important. Thus, time to hand-weed was

likely longer than if weeded by conventional manual laborers. Even though more time was taken per plot than if weeded "in the real world", plants were removed in a similar fashion across all treatments. Grass plants affected by the postemergence herbicide application were not included in the sample.

Plants were sorted into major type groups: broad-leaved (BL) plants, grasses, sedges, and rushes. The number of each plant type present in the sample was determined. The root system was separated from each stem, and pooled samples were oven-dried for at least 36 hr at 60°C to determine stem and root dry biomass. Root and stem biomass for each plant type were combined to give total biomass for each grouping. Numbers of plants, as well as stem and root biomass, from each plant type were then combined to give the total number of plants harvested and total stem and root biomass collected from the postemergence plots.

End-of-season biomass evaluations

All vegetation within a 900-cm^2 area was collected in September of each year (7 Sept., 14 Sept., and 18 Sept. 2000; 12 Sept., 15 Sept., 19 Sept., and 22 Sept. 2001). The sampling area was defined by using an open square frame made of rigid wire. The frame was placed randomly into a plot (avoiding sprinkler heads and previously established problem spots such as bare patches), gently pushed into the vine canopy and positioned as close to the bog surface as possible. Conventional hand clippers were used to cut around the entire inner perimeter to permit collection of cranberry runners or weeds that were passing through the area of the quadrat. Clippers were used belowground in a similar fashion to cut the root systems around the perimeter of the quadrat. Substantial effort was made to collect all plants (stems and roots) present within the sample quadrat.

Initially, sand was gently removed (as much as possible) from the root systems in the field. Samples were then brought into the laboratory and air-dried overnight to permit further removal of sand from the root systems. Samples were stored in brown paper bags at ambient

temperatures until processed. All noncranberry plants were grouped into the "weed" category. Cranberry vines were sorted from weed plants, and root systems of both groups were separated from their respective stems. Stem and root dry biomass for both groups were determined as described above. Stem biomass values of both groups were combined, and the percentage attributable to cranberry vines was determined. The percentage of the root biomass and total (stem plus root) biomass attributable to cranberry vine also was calculated.

Canopy Light Measurements

To obtain data on the amount of photosynthetically active radiation (PAR) that was penetrating the plant (vines and/or weeds) canopy, an EMS-7 canopy transmission meter (PP Systems, Haverhill, MA) was employed. The EMS-7 is a portable system designed for the determination of PAR above and within plant canopies. Readings were taken 5 July 2000, 21 Aug. 2000, 2 July 2001, and 29 Aug. 2001, between the hours of 11 AM to 1 PM (EST), from each nitrogen/density/WMO plot combination. The light meter was placed horizontally into the plot (within the lower portion of plant canopy) along the bog surface. Three individual readings ($\mu mol \cdot m^{-2} \cdot s^{-1}$) were taken and averaged for each plot. Periodically during the sampling session, readings were also taken in full sunlight. The average values were subsequently divided by the "full sun" readings (and multiplied by 100) to calculate the percentage light penetration to the ground surface.

Tissue Analysis

Cranberry vine samples were collected 7-8 Sept. 2000 and 12-15 Sept. 2001 for tissue analysis as per industry recommendations (DeMoranville, 2001). Each 4 x 8 m nitrogen plot was visually split into high-weed (typically, the inoculated and untreated plots) and low-weed

(typically, the pre- and postemergence-treated) areas. Vine samples were collected from these two areas for each nitrogen level, yielding a total of 32 samples per year. Samples were sent to University of Massachusetts Soil and Tissue Testing Laboratory, Amherst, MA for analysis. Standard analytical procedures were used (Jones et al., 1991) including split sample preparation. A portion of the sample was destructed by high temperature oxidation, and the dry ashed tissue was analyzed (for all nutrients other than nitrogen) by inductively coupled plasma emission spectrometry (ICP), and a portion of the sample was subjected to Kjeldahl digestion and colorimetric nitrogen determination. Samples were analyzed for nitrogen, phosphorus, potassium, calcium, and magnesium (%) and zinc, copper, manganese, iron, boron, and aluminum (ppm). Results were then compared to tissue nutrient standards accepted by the industry (Davenport et al., 1995).

Water Sample Collection for Nitrogen Analysis

Water samples were collected from 16 sites located within the experimental plots (numbered black circles in Appendix B.1). The purpose of these samplings was to examine and document variations in ammonia-N and nitrate-N concentrations in the ground water as the planting became established. Perforated PVC pipes (5-cm diameter and 1-m length) were covered with a flexible screen sleeve (to filter out soil) and pushed into the ground, with approximately 20 cm of the pipe extended above the planting surface. Removable plastic caps were placed on the top of each pipe to limit the entrance of extraneous debris. A graduated cylinder, securely attached to a long narrow tube, was used to collect the water. During the week between fertilizer applications, approximately 60 ml water was collected by dipping the sampling apparatus into each PVC pipe.

Water was collected 23 May (prior to first fertilizer application), 5 June, 19 June, 3 July, 17 July, 3 Aug., and 21 Aug. 2000; and 10 May (prior to first fertilizer application for the second

season), 29 May, 5 June, 20 June, 6 July, 18 July and 13 Aug. 2001. Water samples were stored at 5°C until the end of the season, and then sent to Mid-West Laboratories, Omaha, NE for nitrate-nitrogen and ammonical-nitrogen analysis. Standard operating procedures for nitrogen analysis were developed by Mid-West Laboratories from methods published by the Environmental Protection Agency (EPA) Office of Research and Development (EPA Method, 1993a; EPA Method, 1993b). Ammonical-nitrogen and nitrate-nitrogen were analyzed using a Flow Solution III (O.I. Analytical, College Park, TX). EPA method 350.1 involves use of colorimetric automated phenate. EPA method 353.2 is used to determine the nitrate/nitrite or nitrite concentration in waters and solids by segmented flow analysis using a cadmium reduction column.

Statistical Analyses

The experimental design for this study was a randomized-complete-block-split-split-plot design with nitrogen rate as the main plot, vine density as the subplot and weed management option (WMO) as the sub-subplot. Treatments were replicated four times within each level for a total of 256 experimental units.

ANOVA was used to test for treatment effects and interactions for all data. Model assumptions were tested through residual analyses (Bowley, 1995). SAS code including Proc GLM, Proc Plot, and Proc Univariate was used to calculate and plot the pattern of the residuals. The Shapiro-Wilk statistic was used to test if the error distribution departed from normality. Many parameters had to be transformed to meet model assumptions and are mentioned specifically in the beginning of each subsection in the Results section. If no mention of transformation is noted in the Results section, data met model assumptions without transformation. Analyses were performed on the transformed data and the means of the

transformed data. To facilitate reader understanding, means were back-transformed to their original units for tabular and graphical presentation.

SAS Version 8.2 (SAS Institute, Inc., Cary, NC) was used as the statistical analysis software package. If year*treatment interactions were not significant ($P>0.05$), data from Year 1 and Year 2 were pooled for further analysis. Most parameters had significant year*treatment interactions, and these parameters were analyzed by each year. Year was significant for almost every parameter measured in this study, as would be expected when a fruit crop exhibits alternate bearing (Eaton, 1978; Strik et al., 1991; Roper et al., 1993). F tests for main treatment effects and year*treatment interactions (as well as other interactions) for this study are listed in Appendices B.2 through B.8.

Computed means for analyzed parameters are presented in the tables, and treatment effects are presented in the figures. Orthogonal polynomial contrasts were used to describe the best-fit relationships for significant continuous main effects and their interactions. Significant treatment levels that could be legitimately tested for best fit were determined by utilizing partitioning of the sum of squares via SLICE option in SAS Proc Mixed. Significant noncontinuous main effects (i.e., WMO) were separated by Kramer-adjusted Tukey's HSD ($P\leq0.05$). Significant interactions with WMO were separated by pairwise comparisons utilizing a Bonferroni correction. Summary tables of F tests from significant orthogonal polynomial contrasts and interactions may be found in Appendices B.9 through B.14.

Abbreviations have been used periodically to simplify expression of treatment effects and their interactions. For the purposes of the subsequent discussion, the following abbreviations may be found in the text:

N = nitrogen rate	Zero-N = 0 $kg \cdot ha^{-1}$
D = vine density	Low-N = 28 $kg \cdot ha^{-1}$
WMO = weed management option	Med(ium)-N = 56 $kg \cdot ha^{-1}$
Pre = preemergence treatment	High-N = 112 $kg \cdot ha^{-1}$

Post = postemergence treatment

Inoc = inoculated treatment

Unt = untreated control

BL = broad-leaved weeds

Σ 'plant group' = root + stem biomass

Zero-D = 0 $t \cdot ha^{-1}$

Low-D = 1.8 $t \cdot ha^{-1}$

Med(ium)-D = 3.6 $t \cdot ha^{-1}$

High-D = 5.4 $t \cdot ha^{-1}$

Y = year

Interactions are linked by an asterisk (*). Abbreviations for treatment combinations are listed by split-plot order when appropriate and separated by slashes, e.g. Low-N/Zero-D/Inoc.

Results

Preemergence WMO Biomass

Data for number of grass shoots were log-transformed, and grass stem and root biomass were transformed by square root-arcsine computations to meet ANOVA model assumptions. Back-transformed data are presented in Tables 3.1 and 3.2. Data were pooled across years for all variables except grass root dry biomass (Appendices B.2 and B.3). P-values for orthogonal polynomial contrasts are listed in Appendices B.9, B.10, and B.11.

During the first two years of growth, nitrogen rate affected number of shoots, stem length, and grass stem dry biomass. Based on orthogonal polynomial contrasts, grass stem length and biomass were best fit to a linear relationship. Number of shoots had significant linear and quadratic components. Figure 3.1 shows that stem dry biomass, stem length, and number of shoots increased as nitrogen rate increased. The effect of vine density on root dry biomass varied by year. Though no significant treatment effects were noted in Year 1, the general trend was increasing grass root biomass with increasing vine density (Zero-D and Low-D = 6.4 $g \cdot m^{-2}$, Med-D = 8.6 $g \cdot m^{-2}$, and High-D = 10.9 $g \cdot m^{-2}$). The opposite trend was seen in Year 2 as grass root dry

biomass decreased as vine density increased, and was best fit to a linear relationship (Figure 3.2). Nitrogen positively affected three out of the four measured biomass parameters for the Pre-WMO plots (Figure 3.3).

Postemergence WMO Effects on Weed Biomass Production

Count data for individuals of each plant group were log-transformed; all other variables were converted to square root-arcsine values except for time (to hand-weed plots), which was transformed by square root only. Year*treatment was significant for several parameters, but time needed to hand-weed plots was the only parameter that was significant in Year 1. Overall, treatment effects were observed when data from Year 1 and Year 2 were pooled, or in Year 2 only (Tables 3.3 to 3.9). Appendices B.2 and B.3 list P-values ≤ 0.10 for ANOVA, and significant orthogonal polynomial contrasts and interactions for the postemergence treatment are listed in Appendices B.9, B.10, and B.11.

During the first two years of growth (i.e., years pooled), nitrogen rate affected sedge root dry biomass and total root dry biomass. Sedge and total root biomass increased as nitrogen rate increased (Figure 3.4). Sedge root biomass best fit a linear relationship and total root biomass had significant linear and quadratic components. Vine density affected BL root dry biomass, ΣBL biomass, and total root biomass. Root biomass for these three groups decreased as vine density increased (Figure 3.5), and had significant linear and quadratic components. The effect of vine density on sedge stem dry biomass and ΣSedge varied with nitrogen rate. Partitioning of the sum of squares indicated significance of vine density within the Med-N and High-N levels. For sedge stem biomass, both N rates were best fit to a quadratic relationship. ΣSedge had a linear best-fit relationship for Med-N and a cubic best fit for the High-N rate. The response of sedge stem biomass and ΣSedge followed similar patterns (Figures 3.6 and 3.7, respectively). Sedge

biomass decreased at the Med-N rate as vine density increased. Conversely, sedge biomass in the High-N plots showed peaks in biomass in the Med-D plots.

In Year 2, nitrogen rate affected number of grass, sedge, and total number of stems, grass stem and root dry biomass, and ΣBL and ΣGrass biomass. Numbers of weeds (grass, sedges, and total) and ΣBL and ΣGrass biomass were best fit to a linear relationship (Figure 3.8 and Figure 3.9). Not surprisingly, the number of weeds as well as the total biomass of BL and grass increased as nitrogen rate increased. Grass root dry biomass was best fit to a linear relationship; grass stem biomass had significant linear and quadratic components. Grass stem and root biomass increased as nitrogen rate increased (Figure 3.10).

In Year 2, vine density affected number of BL, grass, and total plants, grass stem and root dry biomass and ΣGrass. Number of sedges was weakly affected by density (P=0.075). Number of weeds decreased as vine density increased (Figure 3.11). Grass number and total number of weeds had significant linear and quadratic components, where as BL number had significant linear, quadratic, and cubic components. The presence of cranberry vines in any density reduced the number of grass and BL individuals and reduced the biomass of these weed groups (Figures 3.5, 3.11, and 3.12). This trend in the reduction of biomass as vine density increased was seen for grass stem and root biomass, and ΣGrass (Figure 3.12). Grass stem and ΣGrass were best fit to a quadratic relationship, whereas grass root biomass was best fit to a linear relationship.

Nitrogen and density interacted to affect the total stem biomass of weeds in Year 2. Partitioning of the sum of squares indicated significance of vine density within the Low-N, Med-N, and High-N levels. Overall, total weed stem biomass decreased when cranberry vines were present at any density (Figure 3.13). As the nitrogen rate increased, the best-fit relationship became more complicated. Low-N rates were best fit to a linear relationship, Med-N rates were best fit to a quadratic relationship, and High-N rates were best fit to a cubic relationship. As illustrated in Figure 3.13, at Low-N rates, weed stem biomass gradually decreased as vine density

increased. At Med-N and High-N rates, the presence of cranberry vines at any density provided significant competition, reducing the production of weed stem biomass. Notably, more weed biomass was produced at the High-N rate than any other N rate.

In both Year 1 and Year 2, nitrogen rate and vine density interacted to affect the time needed to remove weeds (Figure 3.14). Partitioning of the sum of squares indicated significant differences among vine densities within the Med-N and High-N rates in Year 1, and within the Low-N and High-N rates in Year 2. The Med-N rate had significant linear and cubic components, and the High-N rate was best fit to a quadratic relationship in Year 1. The average time needed to weed most plots in Year 1 was between 1 to 5 minutes (Table 3.9), with the Med-N/High-D plots requiring the most time (approximately 5.5 minutes).

By Year 2, the differences between treatment combinations became more pronounced. The best fit for the Low-N rate was quadratic and the High-N rate had significant linear, quadratic, and cubic components. The High-N/Med-D plots were the most time-consuming, averaging 23 minutes to remove weeds. The High-N/High-D plots were a distant second, taking 12.7 minutes to remove the weeds. Even though the amount of biomass (Table 3.8) collected from these plots was fairly equivalent (97.7 and 89.8 $g \cdot m^{-2}$, respectively), High-N/Med-D plots had more plants to remove (752 plants $g \cdot m^{-2}$) than the High-N/High-D (511 plants $g \cdot m^{-2}$).

Postemergence WMO Effects on Individual Plant Groups as %Total Weed Biomass

The proportion of biomass produced by each plant group was calculated as the mean percentage of the total weed biomass. Mean percentage sedge values (%Sedge) were transformed to the square root-arcsine, and all other groups were log-transformed to meet model assumptions. Appendices B.2 and B.3 list P-values ≤ 0.10 for ANOVA, and significant orthogonal polynomial contrasts and interactions for the mean percentages of each group are listed in Appendices B.9 and B.10.

The general trends of %biomass produced by each plant group for Year 1 and Year 2 are depicted, grouped by nitrogen rate, in Figures 3.15 and 3.16, respectively. In both years, sedges and BL produced more biomass than rushes and grasses. Even though no strong trend was evident in Year 1, %Sedge was generally higher than %BL at Zero-N and High-N rates, and %BL was higher at Low-N and Med-N rates. Grasses or rushes never accounted for more than 24% of the total weed biomass in Year 1. The postemergence spray of the selective grass herbicide, sethoxydim, was effective in most instances and minimal grass biomass was harvested. Grass, however, was prominent in the Low-N/Zero-D (51%) and the Med-N/Zero-D (46%) and all High-N plots in Year 2 (32% to 54%).

Though the range of contribution was wide (6% to 75%), sedges continued to account for a large proportion of the biomass in most treatment combinations in Year 2. Sedges were dominant in the Zero-N/Zero-D plots (75%). Compared to the other groups, sedges (represented mostly by *Cyperus dentatus*) seem to compete well against cranberry. Sedges typically accounted for the majority of the weed biomass (ranged from 30% to 62%), especially in the Med-D and High-D plots that received some nitrogen. Grasses were weaker competitors and were prominent in the Zero-D plots at all N rates except Zero-N. Rushes were most productive when cranberry vines were present but not dominant, contributing approximately 35% of the total weed biomass in the Zero-N/Low-D, Low-N/Low-D, and Med-N/Med-D plots. Broad-leaved weeds were dominant in Zero-N/High-D (56%). Though not dominant, BL were always present in other treatment combinations, typically contributing 15% to 30% of the weed biomass.

Some of these general trends were substantiated by analysis of treatment effects. Vine density affected mean %Sedge and %Grass during the first two years. %Sedge had significant linear and quadratic components. %Grass decreased linearly as vine density increased, and %Sedge increased as vine density increased (Figure 3.17). This is not unexpected as grass biomass had negative trends with density (Figures 3.11 and 3.12), and sedge biomass generally increased with density at High-N levels (Figure 3.6 and Figure 3.7). Nitrogen affected %Grass in

Year 2 only (Figure 3.18), best fit to a linear relationship. As noted above, grass biomass accounted for a large portion of the weed biomass (Figure 3.16) at all rates except Zero-N. Nitrogen had a positive effect on most measured parameters for the Post-WMO plots (Figure 3.19); weed biomass production intensified at the High-N treatment.

Cranberry Biomass Evaluations

Mean values for cranberry stem, root, and total dry biomass are presented in Table 3.10. To meet ANOVA model assumptions, all cranberry biomass variables were log-transformed. Percentage data (cranberry biomass as percentage of total biomass) were transformed by arcsine-square root calculations. Results from all F tests are presented in Appendices B.4, B.5, and B.12.

Nitrogen rate and density interacted in Year 1 and Year 2 to affect cranberry stem and total dry biomass (Figure 3.20). Even though N*D for total cranberry biomass in Year 1 was just above the conventional cut-off for significance (P=0.054), data are presented for each year since overall N*D, N*D for year 2, and N*D*Y were highly significant ($P \leq 0.009$ for all three interactions). Partitioning of the sum of squares indicated significant effects of vine density at all nitrogen levels for both years. Orthogonal polynomial contrasts indicated significant linear, quadratic and cubic components at all nitrogen rates in Year 1 and Year 2 for both parameters.

Total and cranberry stem biomass gave similar trends. For simplicity, only total cranberry biomass will be discussed, but relationships for N*D interaction may be extended to cranberry stem biomass as well. By the end of Year 1, all plots had less biomass than originally planted (Low-D=180 $g \cdot m^{-2}$, Med-D=360 $g \cdot m^{-2}$, and High-D=540 $g \cdot m^{-2}$) except the High-N/Low-D plots (202 $g \cdot m^{-2}$). This is not an unexpected result, since vines are intentionally pressed belowground during the disking process (Sandler, 1998; DeMoranville et al., 2001). A portion of the vines successfully established; this portion was then sampled and measured as biomass. By the end of Year 2, plots receiving zero N at Low-D, Med-D, and High-D had less biomass than

the initial vine density (actual values = 179, 262, and 332 $g \cdot m^{-2}$, respectively). Even though biomass increased as vine density increased in plots receiving zero N, biomass amounts from Zero-N/Zero-D and Zero-N/Low-D corresponded to less than 25% vine coverage (see Chap. 4).

By the end of Year 2, larger differences in total biomass were seen as vine density increased for Low-N, Med-N, and High-N rates. At low densities, Low-N rates increased biomass by 70% compared to Zero-N rates; High-N and Med-N rates increased biomass 210% and 215%, respectively. Similarly, at Med-D, Low-N rates increased biomass by 100% compared to Zero-N rates; Med-N and High-N rates increased biomass 160% and 210%, respectively. Increases with High-D plantings were slightly lower. At high densities, Low-N rates increased biomass by 75% compared to Zero-N rates; Med-N and High-N rates increased biomass 120% and 155%, respectively.

Cranberry stem and total cranberry dry biomass were also influenced by weed management option during the first two years (Figure 3.21). Means (year data pooled) were separated according to Kramer-adjusted Tukey's HSD ($P \leq 0.05$). Pre-WMO and Post-WMO had more total cranberry biomass than Inoc-WMO. Pre-WMO plots had more cranberry biomass than untreated plots. Post-WMO plots were similar to untreated plots, and Unt-WMO had similar amounts of biomass as Inoc-WMO.

Cranberry root dry biomass also showed no year*treatment interactions, and data were pooled for analysis. The effect of WMO on cranberry root biomass varied with vine density. Partitioning of the sum of squares for the D*WMO interaction indicated significant differences among WMO treatments for Low-D and High-D. At low-density plantings, cranberry root biomass (Figure 3.22) was higher in Pre-WMO plots compared to inoculated and untreated plots (according to t-test using Bonferroni correction, $P \leq 0.008$). At the high-density plantings, all WMO had higher cranberry root biomass than the inoculated plots. Preemergence herbicide treatment was important for production of cranberry roots at low vine densities; at the high density, WMO had minimal impact on root production.

End-of-Season Weed Biomass

To meet ANOVA model assumptions, all weed biomass variables were log-transformed. Percentage data (cranberry biomass as percentage of total biomass) were transformed by arcsine-square root calculations. Results from all F tests are presented in Appendices B.4, B.5, and B.12.

The effect of weed management option on all weed biomass parameters (Table 3.11) varied with nitrogen rate, across years. Partitioning of the sum of squares for the N*WMO interaction indicated significance among WMO treatments within all nitrogen levels for all parameters. During the first two years, Pre-WMO and Post-WMO plots had lower weed dry biomass (stems, roots, and total) than inoculated or untreated plots (Figure 3.23) for all N levels. The inoculated and untreated plots had similar amounts of weed biomass. At zero N, Pre-WMO and Post-WMO plots produced similar amounts of weed biomass. Slightly higher weed root biomass was produced in the Pre-WMO plots than the Post-WMO plots at the High-N rate; no differences were seen in root biomass at Low-N and Med-N rates. Higher amounts of stem and total weed biomass were produced at Low-N, Med-N, and High-N rates in the preemergence plots compared to the postemergence plots. Since the Post-WMO plots were hand-weeded approximately 7 weeks prior to the end-of-season biomass collection, it is not surprising that slightly lower biomass amounts were collected from these plots. Given these considerations, Pre-WMO and Post-WMO gave virtually similar weed control, when N was present, compared to the inoculated and untreated.

In addition, the effect of WMO on weed stem and total weed biomass varied by density within each nitrogen rate (Figure 3.24). Partitioning of the sum of squares for the N*D*WMO interaction (year data pooled) indicated significance among WMO levels within all N*D combinations for stem and total weed dry biomass. Even though the following discussion focuses on total weed dry biomass, trends were similar for both stem and total dry biomass and may be

extended to include weed stem dry biomass. For all levels of nitrogen, Inoc-WMO and Unt-WMO plots had higher total weed dry biomass than Post-WMO plots at all vine densities.

Trends for comparisons of Inoc-WMO and Unt-WMO plots with Pre-WMO plots were similar to that seen for Post-WMO, but had one exception. At medium nitrogen, Med-N/Zero-D/Pre plots had similar weed biomass to Med-N/Zero-D/Unt plots ($P=0.012$; Bonferroni correction cut-off, $P\leq0.008$). Although not sorted statistically, the herbicide-treated plots had less weed biomass than the untreated plots. Thus overall, Pre-WMO plots had less weed biomass than untreated or inoculated plots at all nitrogen levels for all vine densities.

Inoculated plots and untreated plots produced similar weed stem and total biomass. In general, Pre-WMO and Post-WMO plots produced similar weed stem and total biomass. A few specific exceptions were noted. Med-N/Zero-D/Pre and Med-N/High-D/Pre plots had higher weed biomass than Post-WMO in the same treatment combinations (Figure 3.24). All density/Pre-WMO combinations with high N (except medium density) had higher weed biomass than postemergence plots. As mentioned above, since postemergence plots were hand-weeded in late summer, it is not unexpected that Post-WMO had less end-of-season weed biomass (collected about 7 wk after hand weeding) than the Pre-WMO plots.

To examine the effect of vine density and nitrogen when weeds were not controlled, total weed biomass produced in the Unt-WMO was analyzed. Total weed biomass increased linearly (though weakly) as nitrogen increased in Year 1; vine density had no impact. In Year 2, nitrogen rate and vine density interacted to affect total weed biomass in the Unt-WMO (Figure 3.24B). Partitioning of the sum of squares for the N*D interaction indicated significance among vine densities for the High-N rate. The reduction of total weed biomass with increasing vine density at the High-N rate was best fit to a quadratic relationship.

Weed root dry biomass was affected by density in Year 1 and Year 2. The best fit for Year 1 was quadratic, though this was a weak relationship ($P=0.074$). Even though weed root dry biomass was highest in the high-density planting, the data were quite variable for root biomass in

Year 1 and obscured any notable trend (Figure 3.25). By Year 2, a definable trend was apparent. The best fit was linear; weed root dry biomass decreased as cranberry vine density increased.

Cranberry as Percentage of Total Biomass

Absolute cranberry biomass values may not necessarily express all pertinent information to allow evaluation of treatment effects for cranberry biomass production. Although some treatments produced large amounts of cranberry biomass, large amounts of weed biomass were also produced in these same plots. Thus, the effect of treatment on cranberry biomass values, expressed as a percentage (Table 3.12) of total biomass (weeds plus cranberry), was also analyzed. The effect of vine density on percentage of cranberry of the aboveground biomass (%Above) and percentage of cranberry of the total biomass (%Total) varied with nitrogen application (Figure 3.26) for the first two years. Partitioning of the sum of squares for the N*D interaction indicated significance among density within all nitrogen levels for both variables. %Above and %Total had significant linear, quadratic and cubic components. N*D varied by year for percentage of cranberry of belowground biomass (%Below); this interaction was significant for Year 2 only. Partitioning of the sum of squares for the N*D interaction indicated significance among vine density within all nitrogen levels for %Below. Treatment effects for Year 2 had significant linear, quadratic, and cubic components ($P \leq 0.023$) except for Low-N (cubic, $P=0.082$).

When planted at any density (except zero), cranberry vines accounted for 82% to 84% of aboveground biomass for plots that received zero nitrogen. When nitrogen was added, weed biomass increased such that %Above attributable to cranberry dropped to 62% to 75%. The High-N/Low-D had the lowest %Above biomass (62%). The highest %Above value was from Low-N/High-D (75%). Values were slightly different for %Total, but the trends were the same as %Above.

In Year 2, %Below increased as vine density increased at Low-N and High-N rates. %Below followed a pattern similar to %Above and %Total at Zero-N and Med-N, by leveling off at any density where cranberry vines were present (Figure 3.27). When planted at any density (except Zero-D), cranberry vines accounted for 69% to 79% of belowground biomass for Zero-N plots. When nitrogen was added, weed biomass increased such that %Below attributable to cranberry dropped to 33% to 63%. The High-N/Low-D plots had the lowest %Below value (33%). The highest %Below value was from Low-N/High-D plots (63%).

The effect of WMO on %Total varied with nitrogen rate for the first two years (data pooled). Partitioning of the sum of squares for the N*WMO interaction indicated significance among WMO treatments for all nitrogen levels. The N*WMO interaction was also significant for %Above, and followed a similar trend as %Total. Pre-WMO and Post-WMO plots had a higher %Total than Inoc-WMO or Unt-WMO plots (Figure 3.28). Inoculated and untreated plots had similar %Total values; Pre-WMO and Post-WMO also had similar %Total values to each other. The only exception was that High-N/Post plots had a higher %Total than the High-N/Pre plots.

The effect of WMO on %Above, %Below, and %Total varied with density during the first two years (data pooled). Even though D*WMO*Y was significant for %Above ($P=0.0438$), data are presented as pooled, since D*WMO was highly significant for years pooled and for each year ($P<0.0001$) and data trends were similar. Partitioning of the sum of squares for the D*WMO interaction indicated significance among WMO treatments within all vine densities (except Zero-D) for all three variables. Across low, medium, and high vine densities, Pre-WMO and Post-WMO had a higher percentage cranberry biomass than Inoc-WMO and Unt-WMO during the first two years (Figure 3.29). Inoculated and untreated plots had similar %Above, %Below, and %Total to each other. High-D/Post had similar %Above to High-D/Pre, and all density combinations of Pre-WMO and Post-WMO had similar %Below and %Total values. Cranberry roots accounted for only 35% (Low-D/Inoc) to a maximum of 45% (Med-D/Unt and High-D/Unt) of the belowground biomass in the inoculated and untreated plots. In contrast, cranberry roots

accounted for 78% (minimum in Low-D/Post) to 87% (maximum in Med-D/Post and High-D/Post) of the belowground biomass in the plots treated with weed management.

Percentage Light Penetration

Percentage light penetration (%P) was determined on four dates during the course of the study. Percentage penetration data were transformed by arcsine-square root calculations to make data adhere to ANOVA model assumptions. Date*treatment interactions were significant (Appendix B.6) and data for dates are presented separately (Table 3.13). P-values from orthogonal polynomial contrasts for %P are presented in Appendix B.13. No single treatment or interaction consistently affected percentage light penetration.

The effect of weed management on %P in July 2000, August 2000, and August 2001 (Figure 3.30) varied with nitrogen. Partitioning of the sum of squares indicated significance among WMO levels at the Med-N and High-N rates for July 2000; all N rates for August 2000; and all N rates except Zero-N in August 2001. Pre-WMO had greater %P than Inoc-WMO and Unt-WMO at Med-N and High-N rates in July 2000. Post-WMO had greater %P than Inoc-WMO and Unt-WMO at the High-N rate only. Similarly in August 2000, Pre-WMO and Post-WMO had higher %P than Inoc-WMO and Unt-WMO at all N rates except when compared to Zero-N/Inoc. In August 2001, Pre-WMO and Post-WMO had higher %P than Unt-WMO at the three N rates (Figure 3.30). Pre-WMO had higher %P than the Inoc-WMO only at the High-N rates, while Post-WMO had higher %P than Inoc-WMO at both Med-N and High-N rates.

The effect of vine density on %P varied with nitrogen (Figure 3.31) in August 2000 and August 2001. Partitioning of the sum of squares indicated significance among vine densities at the Med-N rates for August 2000 and all N rates in August 2001. The Med-N rate had significant linear and cubic components. High %P values were in the Zero-D and Med-D plots. No strong trend was evident. By the end of Year 2, density at the Zero-N and Low-N rates were best fit to a

linear relationship; %P declined as vine density increased. The best-fit relationship for the Med-N rate contained significant linear, quadratic and cubic components; the low %P values were in the Low-D plots and the highest %P was in the Zero-D plots. The High-N rate was best fit to a quadratic relationship. The Zero-D plots had the highest %P; %P decreased and leveled off as vine density increased.

Nitrogen, density, and WMO affected %P in July 2001 (Figure 3.32). The best fit with nitrogen was a cubic relationship; though the trend was somewhat level at the lower N rates, %P dropped steeply as nitrogen rate increased (Figure 3.32A). Percentage penetration decreased as vine density increased with significant linear and quadratic components forming the best-fit relationship (Figure 3.32B). The relationship was strongly linear with %P decreasing as vine density increased, from Zero-D (85.3%P) to High-D (65.7%P). Unt-WMO plots had the lowest %P (66.3%) compared to all other WMO according to Kramer-adjusted Tukey HSD (Figure 3.32C).

At the fourth sampling date (August 2001), the effect of WMO varied with density. Partitioning of the sum of squares indicated significance among WMO levels at all vine densities. In the Zero-D plots, Post-WMO had the highest %P (Figure 3.33), followed by Pre-WMO. For Low-D, Med-D, and High-D plots, Pre-WMO and Post-WMO had greater %P than Unt-WMO; comparisons with Inoc-WMO were variable. Inoc-WMO and Unt-WMO had similar %P values at all N rates.

Nutrient Analysis of Cranberry Tissue

Vine samples were specifically collected from high-weed and low-weed pressure areas within each nitrogen level to evaluate rate effects on vines grown in low-weed and high-weed areas (low vs. high weed pressure). Vine samples were analyzed for nutrient content (Tables 3.14 and 3.15). All data met model assumptions without transformation. Both nitrogen*year and

weeds*year interactions were P>0.05 for potassium (K), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and aluminum (Al), and data were pooled across year for these elements (Appendix B.7). P-values for orthogonal polynomial contrasts are listed in Appendix B.14. Nutrients levels that were affected by N*Y interactions ($P \leq 0.05$) are discussed first.

The best-fit relationship for nitrogen rate application for the elements nitrogen and calcium (Ca) was linear in Year 1 and quadratic in Year 2. Boron (B) had significant linear, quadratic and cubic components in Year 1, and significant linear and quadratic components in Year 2. Phosphorus (P) was best-fit to a linear relationship in Year 1 for nitrogen rate, and the effect of weed presence on P levels varied with nitrogen application in Year 2. The response of zinc (Zn) levels to nitrogen rate was best fit to a cubic relationship in Year 1 and to a quadratic relationship in Year 2.

In Years 1 and 2, nitrogen concentrations in cranberry tissues increased as fertilizer rate increased (Figure 3.34). Vines receiving High-N rates exceeded recommended nitrogen tissue levels in both years (Hart et al., 2000). Vines receiving no nitrogen were below or borderline acceptable tissue levels. In Year 1, P levels increased as nitrogen rate increased (Figure 3.35). All samples were within normal P levels. Partitioning of the sum of squares for the N*Weed interaction indicated higher P levels for the Med-N and High-N rates in Year 2. Significance of weed presence was determined by pairwise comparison with Bonferroni corrected p-values. Although vines in low-weed areas had higher P levels than vines in high-weed areas at both Med-N and High-N rates, all values still fell within the normal range (Figure 3.36).

In Year 1 and Year 2, calcium levels decreased with increasing nitrogen rate (Figure 3.37). Calcium levels were slightly above normal values (Davenport et al., 1995) for the Zero-N plots in Year 2. During the first two years, vines in low-weed areas had lower calcium levels than vines in high-weed areas (Figure 3.38). Even with these treatment effects, Ca levels were generally within the normal range. All values for Zn were also within standard acceptable range, even though the specific response of Zn concentrations varied with nitrogen application in Year 1

and Year 2 (Figure 3.39). Highest Zn levels for each year were in the Zero-N plots. During the first two years, vines in high-weed areas had higher Zn concentrations than vines in low-weed areas (Figure 3.40). Boron concentrations followed a similar trend to that of Zn (Figures 3.41 and 3.42). All values were within standard range.

The effect of weed presence on potassium (K) levels varied with nitrogen rate for the first two years. Partitioning of the sum of squares for the N*Weed interaction indicated significance among weed level for all nitrogen rates for K during the first two years of vine growth. Vines in the low-weed areas had higher K levels than vines in the high-weed areas at all nitrogen rates (Figure 3.43); mean separations were very highly significant ($P \leq 0.002$) at all rates except zero nitrogen input ($P=0.018$). Vines receiving High-N rates in both high-weed and low-weed areas had excessive levels of potassium.

The effect of nitrogen rate and weed presence on Mn, Fe, Al, Mg, and Cu levels were analyzed with pooled data from Years 1 and 2. Iron and aluminum levels were affected by nitrogen level and had significant linear, quadratic, and cubic components. Levels for both elements were highest in vines receiving Zero-N (Figure 3.44). Iron levels are considered problematic only if below 20 ppm (DeMoranville, 2001); all values were above this level. Currently, no standards are available for Al concentrations in cranberry leaf tissue (J. Davenport, Washington State University, and T. Roper, University of Wisconsin-Madison, personal communication).

Mn levels were best fit with both linear and quadratic components. Mn concentrations decreased as nitrogen rate increased (Figure 3.45) during the first two years of growth. Vines receiving Zero-N had manganese levels that could be problematic (excessive) in a commercial setting. Although levels varied for the other nitrogen rates, all values were within an acceptable range. Similar to Zn and B, vines in high-weed areas had higher Mn levels than vines in low-weed areas (Figure 3.46).

The best fit for Mg levels to nitrogen rate was linear. Magnesium concentrations decreased as nitrogen rate increased (Figure 3.47). All values were within acceptable industry standards. Vines in high-weed areas had higher levels of Mg than vines growing in low-weed areas (Figure 3.48). Lastly, all treatment effects for copper concentrations were $P>0.05$.

Water Analysis for Nitrate-N and Ammonia-N

Water samples were analyzed for NO_3-N and NH_3-N. Data met model assumptions without requiring transformation. Pipes were located in the center of each fertilizer plot (four pipes each for zero, low, medium, and high nitrogen rates; see Appendix B.1). Samples were taken periodically during the season, at midway points between fertilizer applications. Mean concentrations for nitrite-N and ammonia-N, sorted by treatment and sampling date, are presented in Table 3.16. ANOVA indicated no significant treatment effects for nitrate-nitrogen, ammonical-nitrogen, or total nitrogen (Appendix B.8). Ammonical-nitrogen and total nitrogen concentration varied with year and date. As would be expected in acid soils, ammonium was more prevalent than nitrate (Rorison, 1986).

Perhaps an occurrence of note is that ammonium levels were much higher in Year 1 than Year 2. Levels ranged from 1.43 to 6.88 ppm in Year 1. Levels in Year 2 never exceeded 1.15 ppm. More applied nitrogen was being taken up by plants on the bog surface as the planting became established. Whether cranberry vines or weed species were differentially responsible for nitrogen uptake could not be discerned from this study.

It was hoped that these data would produce a pattern of nitrogen movement across the bog. However, the placement of pipes within each nitrogen level only permitted statistical evaluation of treatment effects. Different N rates overlapped with each other at many sampling pipes, confounding the tracking of N movement. A better design might include application of a known amount of fertilizer at a central point with sampling pipes radiating from this central point.

Flow rates, rainfall, and irrigation events should be tracked. Fertilizer applications would be spatially separated from each other. Various N concentrations could be mapped to determine if varying amounts moved farther or faster than other N rates.

Yield

No yield data were collected in 2000 as the vines were newly planted. Unfortunately, no yield data were collected from the study in 2001 due to an infestation of insecticide-resistant cranberry weevils (*Anthonomus musculus*) on the UMass State Bog. The vines used in the study were 2-yr old c.v. Stevens. This high-yielding, vigorous hybrid is gaining in popularity in the Massachusetts industry, especially for use in new plantings. Though seldom prolific enough for measurable market returns, it was reasonable to expect some initial fruit production from this cultivar (Sandler, 1997a). Unfortunately, the weevil infestation was severe and no viable insect management options were available in 2001. In some locations of the production area, zero fruit were produced. The total yield of the UMass Cranberry Station State Bog, East Wareham, MA in 2001 was reduced by 80%, with the Stevens variety severely impacted (C.J. DeMoranville, personal communication).

Plots will be maintained for at least two more years (through the 2003 field season) to collect additional yield data. In addition to the evaluation of treatment effects on yield, additional relationships to be explored will include effect of weed biomass on cranberry yield. Any findings will be presented in future publications.

Discussion

Weed response in Pre-WMO and Post-WMO plots

Nitrogen positively affected three out of the four measured biomass parameters for the Pre-WMO plots (Figure 3.3). The increase in grass biomass with increased nitrogen inputs is a reasonable response given the importance of nitrogen in plant growth (Barker and Mills, 1980). Overall, vine density did not affect the measured parameters. The only exception was a decrease in grass root biomass as vine density increased in Year 2. Since cranberry biomass samples were not collected at the same time, it is difficult to determine if this decrease in grass root biomass was related to an increase in cranberry root biomass. Even though cranberry biomass was collected in the fall, end-of-season biomass evaluations grouped all weed species together. Based on relative abundance data presented in Chapter 4, grasses were more prominent in Zero-D plots compared to other densities. The data trends indicated that cranberry started to gain a competitive advantage against the grasses as the vines became more established and dense.

Early evaluation of the effects of nitrogen and vine density for Pre-WMO may have been improved by including the collection of *Cyperus dentatus* (nutsedge), a weed that napropamide should control (United Phosphorus, 2003) along with the collected grass biomass. Grower experience has indicated control with napropamide to be fair to moderate for nutsedge. Indirect evidence from other parts of this study indicated that napropamide was suppressing nutsedge, especially in Year 1. Though presented in more detail in Chapter 4, some data are presented here to illustrate treatment effects on *C. dentatus*. *C. dentatus* only occurred 18 times in Year 1 in the Pre-WMO plots compared to 48, 52, and 41 times in Post-WMO, Inoc-WMO, and Unt-WMO, respectively. After two years, nutsedge coverage in preemergence plots reached a maximum of less than 10%, whereas percent coverage in Post-WMO and Unt-WMO reached a maximum of

41% to 60% and Inoc-WMO reached a maximum of 25% to 40%. *C. dentatus* was not very abundant in Pre-WMO plots in Year 1, but was the second most abundant weed in Year 2.

C. dentatus was the only sedge among the dominant species in both Pre-WMO and Post-WMO plots (see Chapter 4). It may be possible that the nitrogen and density effects seen on the sedge group in the Post-WMO would have occurred in the Pre-WMO. However, only grasses, not sedges, were collected. In spite of this data omission that may have enhanced the description of treatment effects for the Pre-WMO, end-of-season biomass collection indicated very good to excellent overall weed control in Pre-WMO plots (Tables 3.11 and 3.12).

Nitrogen had a positive effect on most measured parameters for the Post-WMO plots (Figure 3.19); weed biomass production intensified at the High-N treatment. When nitrogen was abundant, all plant species were able to successfully produce biomass. However, cranberry biomass production was much higher in Year 2 than Year 1 (Tables 3.10 and 3.11); weed biomass did not markedly increase in the second year. Significant density or nitrogen effects on the Post-WMO variables were not evident until the second year of the study or unless year data were pooled (except for time to hand weed). The negative relationships seen between weed performance and vine density could be explained by the increased competition exerted by cranberry as the vines became established. Bare space was very available in Year 1, and nutrients were generally adequate for both the initial weed colonizers and cranberry vines. Thus, density and nitrogen treatments became more important as the planting became established. Rush biomass production was not affected by any nitrogen or density treatment.

Grass and BL biomass, %Grass, total root biomass, and total number of weeds decreased as vine density increased. This concurs with other reported research. The suppression of weed species in the presence of well-established annual crops has been reported (Topham and Lawson, 1982; Staub, 1992). For example, established lowbush blueberry plantings were competitive against bunchberry (*Cornus canadensis* L.) (Yarborough and Bhowmik, 1993). However, unlike any other biomass variable, %Sedge actually increased as cranberry vine density increased.

Other *Cyperus* species are known to be good competitors (Cudney and Holt, 1997; Holm et al., 1997; Moffett and McCloskey, 1998), especially *C. esculentus* (L.) (yellow nutsedge) and *C. rotundus* (L.) (purple nutsedge). Nitrogen and density interacted to affect sedge stem dry biomass, ΣSedge (years pooled), and total weed stem biomass (Year 2 only). Even in these interactions, the positive trend of increasing weed biomass with increasing N rate can be seen (Figures 3.6, 3.7, and 3.13).

Sedges and broad-leaved plants tended to produce more biomass than grasses and rushes at many N*D combinations in the initial stages of vine establishment. In Zero-D plots receiving some nitrogen, grasses became more abundant in Year 2, mostly due to the presence of hairgrass (*Muhlenbergia capallaris* (Lam.) Trin). Grasses were also a large component of the weed biomass when nitrogen was abundant. BL weeds were a small but consistent component of the weed biomass, usually accounting for 15% to 30% of the biomass. Rushes were rarely a significant contributor, but seemed most abundant in Zero-N plots where cranberry was present.

Notably, more total weed biomass was produced at the High-N rate than any other N rate. This suggests that even though cranberry vines could successfully suppress weed biomass at Med-N and High-N rates, abundant nitrogen supported more productive weed populations. Even though the weeds produced more biomass as N rate increased, cranberry still accounted for 88% to 99% of the total biomass produced in the Post-WMO plots by the end of Year 2 (Table 3.12).

Time needed to remove weeds was a function of both nitrogen rate and vine density. Higher labor inputs were needed to manage weed populations with postemergence techniques at Med-D and High-D and Med-N and High-N combinations. The most difficult plots to hand-weed received the High-N rate and had moderately dense cranberry coverage (High-N/Med-D plots). Since weeds had to be carefully separated from the vines as to minimize root injury or cranberry vine removal, plots with healthy vine growth with adequate or abundant nitrogen were harder to weed. More open space was typically present in Low-D plots, making these treatments easier to weed since weeds could be quickly pulled out of the ground.

End-of-Season Cranberry and Weed Biomass

Nitrogen rate and vine density interacted to affect cranberry biomass production. Within any vine density (except Zero-D), the greatest production of cranberry biomass after two seasons of growth was noted when nitrogen was applied at 56 kg•ha^{-1} or more. The highest producing combinations were: High-N/High-D (844 g•m^{-2}), High-N/Med-D (817 g•m^{-2}), Med-N/High-D (737 g•m^{-2}), and Med-N/Med-D (679 g•m^{-2}). Weed removal, by preemergence herbicide application or postemergence treatments, was critical for maximizing the production of cranberry biomass in any treatment combination.

Overall, Pre-WMO and Post-WMO similarly reduced the amount of weed biomass compared to both the untreated and inoculated plots. Although there were a few exceptions, nitrogen and WMO were very important factors influencing the production of weed biomass. Vine density was not a significant factor as total weed biomass remained basically stable across all vine densities for Pre-WMO and Post-WMO treatments (Figure 3.24). When weeds are controlled by chemical or mechanical methods, crop density did not seem to play a significant role in determining total weed biomass. However, when weeds were not controlled (Unt-WMO), vine density reduced the production of total weed biomass when nitrogen was highly abundant (Year 2).

Though many studies have demonstrated the negative effect of increasing weed biomass on crop productivity (Kolhe et al., 1988; Staub, 1992; Hogue and Peters, 1994; Merwin and Ray, 1997), few have examined the impact of crop density on weed biomass production. The impact of weeds as competitors or as groundcover management in tree fruits has been an area of recent research (Merwin and Stiles, 1994; Tworkoski and Glenn, 2001). The impact of nitrogen, irrigation, and other cultural practices has been documented for high-density plantings of perennial (Layne et al., 1981; Layne and Tan, 1984; Walsh et al., 1989). From an agricultural

point of view, the impact of various crop densities on weed biomass production may pale in comparison to gaining information on the effects of the lack of weed control on crop productivity. From an ecological perspective, the present study presents new information on the impact of crop density on weed biomass production in a perennial fruit system. In addition, growers attempting to produce cranberries organically may be able to incorporate crop density into their integrated pest management program.

Cranberry as Percentage of Total Plant Biomass

%Above and %Total followed similar trends for significant treatment effects. Adding N increased %Above and %Total at every vine density. Cranberry was able to be relatively productive even in nutrient-poor conditions. Once nitrogen was introduced however, weeds started obtaining nitrogen and producing more biomass. These trends (Figure 3.26) incorporated data across WMO, and the reduction in %Total by N rates can be attributed mostly to the reduction in cranberry biomass in the Inoc-WMO and Unt-WMO (Table 3.12). In general, there was no detrimental effect or improvement in %Total and %Above as nitrogen rate increased.

The response of cranberry as a percentage of total biomass within two-way treatment combinations was variable. Percentage ranges were widest for %Below D*W combinations, from 31% to 87%. %Total in the N*W combination was also fairly wide, ranging from 30% to 74%. %Above and %Total in the N*D combination had the narrowest range of percentage biomass produced as cranberry, 69% to 85%. Managing weeds with either WMO significantly favored cranberry biomass production. Across all vine densities (except zero), %Below was highest in plots that received no nitrogen. Cranberry was capable of substantial root production in minimal nutrient conditions. When nitrogen was available, weeds and cranberry were equally capable of producing biomass (ranged from 48% to 63%) in most instances. Cranberry was least productive, in terms of above, below, and total biomass, at High-N/Low-D treatments.

Cranberry is known to grow better than many non-ericaceous plants in lower nutrient conditions (Addoms and Mounce, 1932; Dirr, 1974). Higher rates of nitrogen promoted increased weed biomass production. The addition of nitrogen, however, was not enough for cranberry to compensate for the low initial vine density. These results indicate that, across all WMO, higher vine densities with lower nitrogen inputs favor cranberry biomass production. The efficiency of various treatment combinations is examined in more detail in Chapter 5.

Weed control was important for producing a substantial proportion of cranberry biomass. Pre-WMO and Post-WMO similarly improved %Total compared to both Inoc-WMO and Unt-WMO. The importance of early weed suppression for establishing a perennial crop has been previously documented in cherry (Al-Hinai and Roper, 2001), grape (Zabadal and Dittmer, 2001), peach (Foy et al., 1996), and apple (White and Holloway, 1967).

Evaluation of Three-way Treatment Combinations

By the end of Year 1, 5 three-way combinations had the highest vine growth: Med-N/Med-D/Post (455 $g \cdot m^{-2}$), Low-N/High-D/Pre (418 $g \cdot m^{-2}$), Low-N/High-D/Post (386 $g \cdot m^{-2}$), Med-N/High-D/Post (372 $g \cdot m^{-2}$), and High-N/High-D/Pre (358 $g \cdot m^{-2}$). Total cranberry biomass production was lowest (excluding Zero-D plots) in the Zero-N/Low-D/Unt (71 $g \cdot m^{-2}$), followed by Low-N/Low-D/Unt (91 $g \cdot m^{-2}$), and Med-N/Low-D/Unt (105 $g \cdot m^{-2}$).

By the end of Year 2, Low-N/Low-D plots did not exceed the amount of biomass originally planted; Low-N plots at medium and high densities produced more biomass than the original planting density, achieving good colonization of the ground surface. Even though the Low-N/Med-D/Pre produced the most biomass in the Low-N group (672 $g \cdot m^{-2}$), overall, no improvement was gained by planting vines at 5.4 $t \cdot ha^{-1}$ rather than 3.6 $t \cdot ha^{-1}$ when at least low rates of nitrogen were added.

Initially, the goal in successful cranberry establishment is to quickly colonize the ground surface with healthy runners (DeMoranville et al., 2001). Upright production must then be promoted as a high percentage of flowering uprights are needed to attain economic yields (Eaton and Kyte, 1978; Eaton et al., 1983). However, excessive nitrogen can cause overgrowth of vegetative plant parts (Eck, 1971; Eck, 1976) in the form of lengthy runner growth and/or overly long uprights (Chandler, 1961). Excessive vine growth (fostered by excessive nitrogen application) is often inversely related to yield (Hart et al., 1990; DeMoranville, 1992), and this condition delays the grower's aim for transitioning into fruit production. From a pest management perspective, excessive vine growth is also problematic because it promotes favorable conditions for fruit rot development (Caruso et al., 2000) and increases the potential for insect damage (Averill and Sylvia, 1998). Biomass production was highest in the High-N/High-D/Pre and High-N/Med-D/Pre plots (1,020 and 1,004 $g \cdot m^{-2}$, respectively); high biomass production was also noted in the High-N/Med-D/Post and High-N/High-D/Post plots (918 and 961 $g \cdot m^{-2}$, respectively).

Based solely on percentage weed biomass reduction compared to the untreated plots (Table 3.11), several treatments had good to excellent weed control. Overall, the Post-WMO treatment had the higher weed biomass reduction than the Pre-WMO (P=0.011). Low-N/High-D/Post, Zero-N/High-D/Post, and Low-N/Med-D/Post had the best weed control (97.7%, 96.1%, and 93.5%, respectively), followed closely by High-N/High-D/Post (92.4%), Zero-N/High-D/Post (91.8%), and Zero-N/Med-D/Post (91.1%). Since the Post-WMO plots were hand-weeded late in the season, it is not unexpected than weed reduction would be very high for this treatment. Even though excellent weed control was attained, several of above combinations contained no cranberry vines. The absence of cranberry vines permitted maximal weed reduction, but would be of little agricultural value to the cranberry farmer.

Unquestionably, examination of gross cranberry biomass production or weed control alone is not necessarily the only way to predict commercial success of a young planting. The

criteria for successful establishment are quick and thorough coverage of the ground surface by runners. However, fruit production is most influenced by the number of flowering uprights and percent fruit set (Eaton and MacPherson, 1978). Once adequate ground colonization is attained, the grower must practice good horticultural techniques (e.g., frost protection, pollination, sanding) to promote the production of uprights and fruit.

The top five three-way combinations, in terms of maximum cranberry and minimum weed biomass (expressed as cranberry as a percentage of total plant biomass, weed + cranberry), without cranberry vines becoming excessive were: Med-N/Med-D/Post, Med-N/High-D/Post, Med-N/Low-D/Pre, Low-N/Med-D/Pre, and Med-N/Low-D/Post (Table 3.17).

The Low-N/Med-D/Pre plots are included in this grouping of promising treatment combinations despite the relatively low %weed reduction. The untreated plot in this combination had the lowest weed biomass (218 $g \cdot m^{-2}$) of any Unt-WMO that received any rate nitrogen (Table 3.11). Thus, even though the amount of weed biomass produced in the Pre-WMO was fairly low (72.4 $g \cdot m^{-2}$), the percentage weed reduction does not appear to be as good as several of the other noted combinations. In addition, the High-N/Low-D/Pre plots had good cranberry biomass production (699 $g \cdot m^{-2}$), but the portion of the total biomass attributable to cranberry dropped to 74% and weed reduction was only 58.4%. Other treatment combinations that produced substantial cranberry biomass, such as High-N/Med-D/Unt (797 $g \cdot m^{-2}$) or Med-N/High-D/Unt (765 $g \cdot m^{-2}$), had much lower values of %Total (57% and 61%, respectively) than the selected treatment combinations noted above.

Light Penetration

The overall trends for %P are best illustrated by the July 2001 (Year 2) sampling date. Even when interacting with WMO, canopy light penetration decreased as nitrogen rate increased and as vine density increased. Plots receiving either Pre-WMO or Post-WMO had higher canopy

light penetration than inoculated and untreated plots. Pre-WMO and Post-WMO plots were statistically similar to each other in most instances. Occasionally, inoculated plots had higher light penetration than untreated plots, but these two treatments were typically similar to each other.

The design of the study hampered extraction and evaluation of treatment effects on additional information, such as radiation use efficiency. PAR readings were conducted under a canopy of mixed plant species. The complexity of the plant community made the evaluation of correlations and other mathematical relationships between light and cranberry biomass problematic. In addition, cranberry biomass was collected in September, whereas PAR readings were made in July and August. To accurately assess radiation use efficiency, biomass should be collected at the time of the PAR reading (Perez de Camacaro et al., 2002).

With these limitations in mind, correlations were run to examine the relationship between %P and %Total (cranberry biomass as a percentage of total plant biomass). For each year, the %P reading from each N*D*WMO combination was paired with the percent cranberry of total biomass data collected from the corresponding plot. Use of untransformed data gave the highest r value for these variables. In Year 1, 19% ($r = 0.44$) of the variation in %Total could be explained by light penetration to the ground. No significant correlations were noted for Year 2. Once cranberries became established (Year 2), other factors were more important in explaining the variation in %Total.

Given a different experimental design, other relationships between light and cranberry biomass could have been pursued. A linear relationship between light interception and dry matter production during the early portion of the growing season has been well documented in the literature (Biscoe and Gallagher, 1977; Landsberg and Cutting, 1977; Hay and Walker, 1992). For reasons stated above, it was not appropriate to analyze the fit of light interception and cranberry biomass. Exploratory tests for light (interception) penetration and %Total indicated that, for Year 1 only, a third order polynomial had the highest R-squared value ($R^2 = 0.39$). Other

research has documented radiation use efficiency when biomass was collected at the time of PAR data collection for strawberry (*Fragaria* x *ananassa*) (Perez de Camacaro et al., 2002) and grains (Gallagher and Biscoe, 1978). The design of the present study does not permit comment on the efficiency of cranberry to produce biomass based on intercepted solar radiation. This could certainly be an area of future research in cranberry physiology.

Leaf Nutrient Content

Levels of Ca, Zn, Mn, B, and Mg were higher in cranberry tissue grown in high-weed pressure areas than that grown in low-weed areas. All levels were within standard ranges. N, Fe, Cu, and Al levels were not affected by weed presence. This contrasts with research in peach where weeds reduced leaf N (Tworkoski and Glenn, 2001). Hicks et al. (1968) reported a decline in chlorophyll in cranberry vines growing in weedy areas compared to a pure stand. Data from this study showed no decreased Mg levels in weedy areas, and cannot offer indirect support of this observation. It should be noted that the Hicks study was conducted on an established bed, and response of nutrient levels may differ in newly planted cranberry vines. Though response varied with nitrogen rate, levels of P and K tended to be higher in cranberry vines growing in low-weed pressure areas. It may not be easy to extrapolate the response of one crop system to another. Merwin and Stiles (1994) showed that both foliar and soil nutrient levels varied with orchard groundcover management. The foliar nutrient content of apple trees, maintained free of weeds (though a fescue sod was established) varied with rootstock and planting density (Schneider et al., 1978).

Levels of N, P, and K increased as nitrogen rate increased. These elements were applied at regular intervals in the fertilizer regime. The levels of Ca, Zn, Mn, B, Fe, Al, and Mg were negatively correlated with nitrogen rate. This is a common response seen in plants in general.

These nutrients were not supplemented as part of the fertilizer regime and as biomass increased, these nutrients became diluted in the tissue.

Conclusions

Nitrogen rate, vine density, and weed management option interacted to influence successful ground colonization by cranberry vines. Weed management, either preemergence or postemergence, is critical for successful vine establishment. Planting at high vine densities could not compensate for lack of weed management, especially when nitrogen was added. When no fertilizer was added, untreated plots (low, medium, and high vine density) produced comparable amounts of cranberry biomass to managed plots. However, none of these Zero-N plots produced commercially adequate amounts of vines by the end of two seasons. The addition of nitrogen was critical for good colonization, but amounts exceeding 56 $kg \cdot ha^{-1}$ gave no improvement in establishment over lower nitrogen rates, and often fostered excessive weed growth.

Post-WMO was more effective in reducing weed biomass than Pre-WMO. Overall, Post-WMO plots achieved 87% weed reduction (compared to the untreated) whereas Pre-WMO plots averaged 69% weed reduction. The most effective treatment combination for managing weeds was Low-N/High-D/Post, which reduced weed biomass 98% compared to its respective untreated control. Across many tested parameters, Pre-WMO and Post-WMO were equivalent in providing weed control. The combination of cranberry vines at any density, with either Pre-WMO or Post-WMO, minimized weed biomass production.

Several nitrogen rate/vine density combinations favored crop biomass production over weed biomass production. At the end of two seasons, Low-N/High-D plots (across all WMO) had the highest percentage cranberry biomass, followed by Low-N/Med-D, and High-N/High-D (76% to 79%). Weed management increased the proportion of biomass attributed to cranberry. Averaging Pre-WMO and Post-WMO, Zero-N/Med-D had the highest percentage cranberry

biomass production followed closely by Zero-N/High-D and Low-N/High-D (96% to 97%). The highest absolute amounts of cranberry biomass were produced in the High-N/Med-D and High-H/High-D plots.

In general, high applications of nitrogen could compensate for low initial planting densities, if weed control was provided. Similar cranberry biomass production was attained in low-density combinations that received medium and high rates of nitrogen as in the high-density planting that received low rates of nitrogen. After two years, the cranberry biomass produced in these combinations yielded about 90% ground cover and would be considered commercially acceptable. Adding moderate to high rates of nitrogen, even with labor included, to a low-density planting is much less expensive than planting vines at a higher density. The Med-N/Low-D combination (with weed management) is a commercially viable option in terms of quickly attaining adequate ground cover.

Based on cranberry biomass production and weed control, several 3-way combinations seem promising as potential management programs that could be utilized by growers: Med-N/Med-D/Post, Med-N/High-D/Post, Med-N/Low-D/Pre, Low-N/Med-D/Pre, and Med-N/Low-D/Post. The relative success of these combinations was evaluated solely on measured biological parameters and did not incorporate economic variables. The most efficient combination(s) based on biological and economic terms are explored and discussed in Chapter 5. With this additional information, other three-way combinations could provide a viable planting scheme for growers depending upon their marketing and farm management goals.

Table 3.1. Stem and root dry biomass of grass plants collected from plots treated with preemergence applications of napropamide (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Preemergence treatments: Stem biomass ($g \cdot m^{-2}$)[z] 2000	Stem biomass ($g \cdot m^{-2}$)[z] 2001	Root biomass ($g \cdot m^{-2}$)[y] 2000	Root biomass ($g \cdot m^{-2}$)[y] 2001
0	0	19.81	6.03	8.18	1.83
	1.8	9.47	0.22	3.88	0.11
	3.6	3.23	0.11	1.94	0.11
	5.4	6.89	0.32	4.31	0.11
28	0	8.18	6.46	3.44	3.12
	1.8	20.13	4.84	9.26	1.72
	3.6	25.83	3.01	10.98	1.83
	5.4	17.22	4.31	7.75	0.97
56	0	16.79	10.98	7.00	3.98
	1.8	11.63	9.26	5.81	1.29
	3.6	19.38	3.44	10.01	1.08
	5.4	47.69	1.08	18.30	0.22
112	0	16.68	14.75	6.78	5.06
	1.8	17.87	18.30	6.78	6.78
	3.6	30.14	14.53	11.63	4.84
	5.4	17.12	6.03	13.24	1.08

[z]Nitrogen affected stem biomass (P=0.033) in the first two years.

[y]Root biomass was affected by nitrogen (P=0.004) and density (P=0.040) in Year 2.

Table 3.2. Number and stem length of grass plants collected from plots treated with preemergence applications of napropamide (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Preemergence treatments: Number ($shoots \cdot m^{-2}$)[z] 2000	Number ($shoots \cdot m^{-2}$)[z] 2001	Stem lengths (mm)[z] 2000	Stem lengths (mm)[z] 2001
0	0	729.5	432.6	53.2	42.0
	1.8	626.2	12.9	51.2	22.7
	3.6	142.0	59.2	39.8	9.6
	5.4	306.7	72.1	79.1	9.6
28	0	1024.4	591.8	41.6	52.5
	1.8	936.1	460.5	54.1	42.2
	3.6	1334.2	335.7	47.1	61.7
	5.4	726.3	482.0	73.4	49.2
56	0	715.5	457.3	60.9	61.1
	1.8	742.4	342.2	52.7	63.4
	3.6	895.2	96.8	64.6	109.1
	5.4	1770.0	209.8	80.0	58.3
112	0	690.8	796.2	47.8	51.7
	1.8	557.4	755.4	70.8	70.5
	3.6	959.8	607.9	56.1	85.5
	5.4	15117.8	182.9	55.8	107.4

[z]For the first two years of growth, nitrogen affected number of shoots and stem length (P=0.008 and P=0.038, respectively).

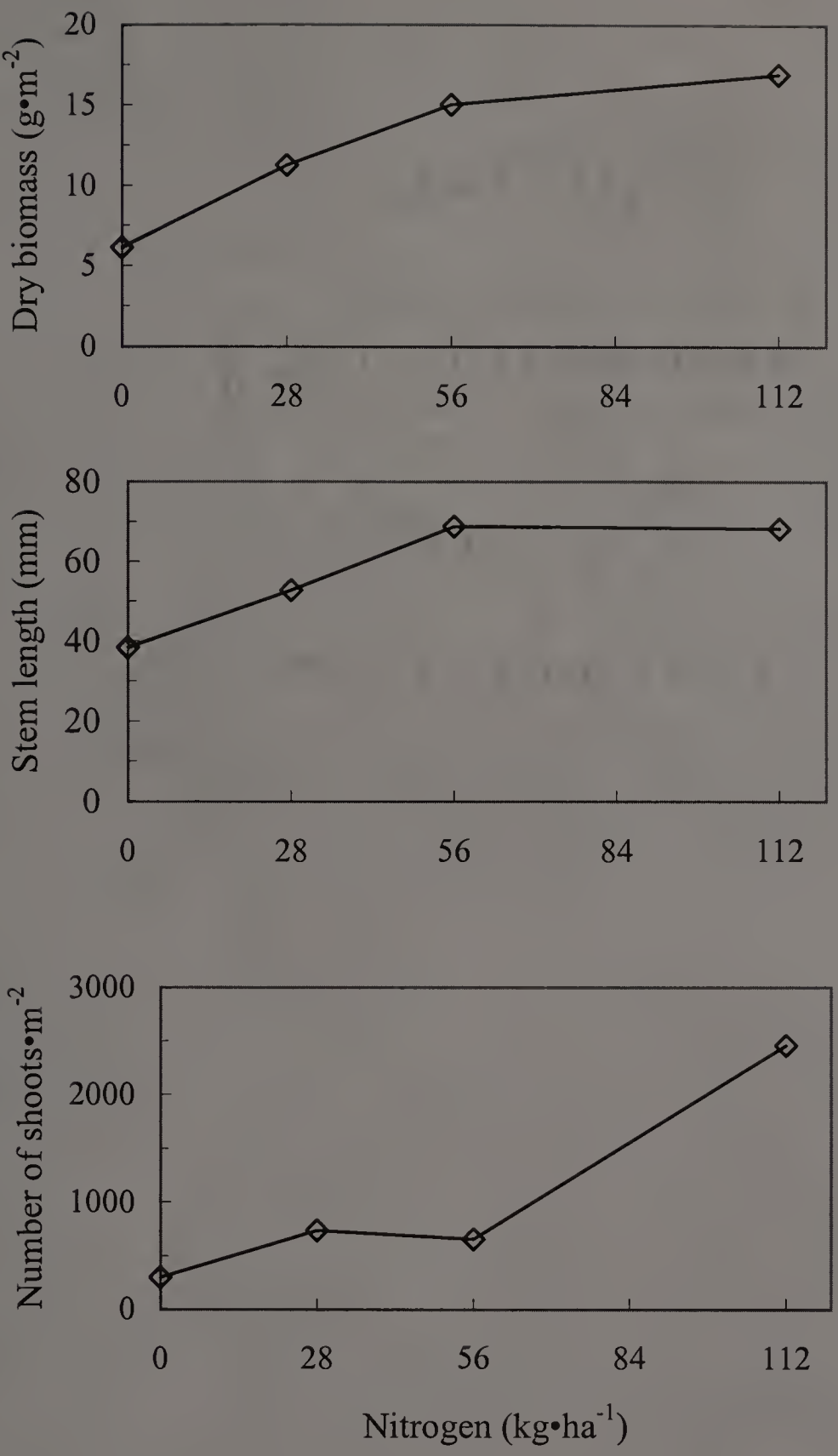

Figure 3.1. Effect of nitrogen rate on grass stem dry biomass, number of shoots, and stem length during the first two years of growth from plots treated with a preemergence application of napropamide (N=32).

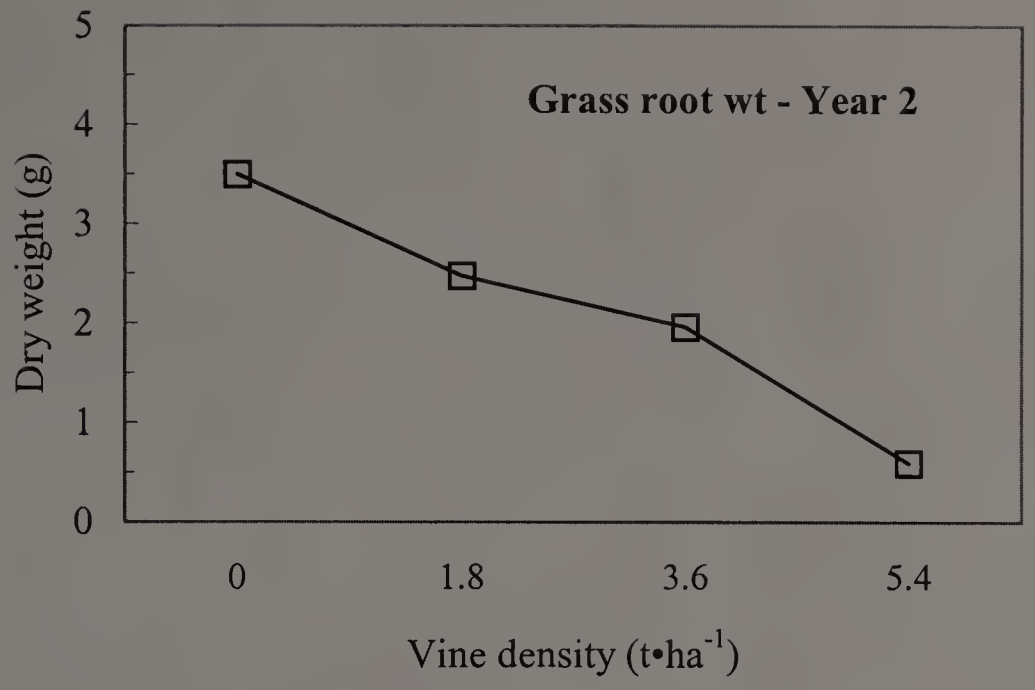

Figure 3.2. Effect of vine density on grass root dry weights collected in Year 2 from plots treated with a preemergence application of napropamide (N=16).

Preemergence

	Nitrogen	Density	N*D
Number of grass shoots	YP		
Grass stem length	YP		
Grass stem weight	YP		
Grass root weight		Y2	

Y2= Year 2 only
YP= Years pooled

negative relationship
positive relationship
no treatment effect

Figure 3.3. Summary of the general trends of nitrogen rate and planting density for preemergence treatments.

Table 3.3. Number of plants and stem and root dry biomass of broad-leaved plants collected from plots receiving postemergence treatments (N=4).

		Broad-leaved plants					
Nitrogen	Vine density	Plants (no.•m^{-2})^{z}		Stem biomass (g•m^{-2})		Root biomass (g•m^{-2})^{y}	
(kg•ha^{-1})	(t•ha^{-1})	2000	2001	2000	2001	2000	2001
0	0	40.8	101.4	6.5	8.6	1.2	2.5
	1.8	10.1	32.3	4.7	3.4	0.9	1.2
	3.6	6.8	10.1	0.9	1.4	0.2	0.5
	5.4	17.1	27.3	2.8	3.8	0.8	1.7
28	0	28.8	226.9	26.6	16.6	9.8	4.4
	1.8	54.6	60.8	26.5	8.4	5.7	2.3
	3.6	22.9	45.8	14.8	7.0	4.3	2.3
	5.4	67.8	53.3	11.3	5.4	2.3	1.0
56	0	44.1	250.3	23.7	34.9	14.9	8.1
	1.8	25.5	69.5	16.6	7.5	2.5	1.9
	3.6	26.6	17.3	10.5	5.2	4.5	2.7
	5.4	89.1	27.5	26.7	8.7	4.8	3.2
112	0	28.8	565.6	11.2	47.3	3.0	12.9
	1.8	11.8	379.9	12.0	12.1	2.1	2.0
	3.6	40.0	36.9	8.0	7.0	2.9	1.0
	5.4	28.1	83.9	10.4	7.7	1.2	3.7

[z]Density affected number of plants (P=0.001) in Year 2.

[y]Density affected root dry weight (P=0.046) for the first two years.

Table 3.4. Number of plants and stem and root dry biomass of grasses collected from plots treated with postemergence treatments (N=4).

		Grasses					
Nitrogen	Vine density	Plants (no.•m^{-2})^{z}		Stem biomass (g•m^{-2})^{z}		Root biomass (g•m^{-2})^{z}	
(kg•ha^{-1})	(t•ha^{-1})	2000	2001	2000	2001	2000	2001
0	0	11.8	142.6	2.9	10.8	1.6	3.1
	1.8	2.1	18.6	0.2	0.9	0.0	0.2
	3.6	0.6	2.5	0.4	0.1	0.1	0.1
	5.4	0.0	6.9	0.0	0.4	0.0	0.1
28	0	3.0	448.1	0.5	27.8	0.1	4.2
	1.8	0.0	35.0	0.0	1.8	0.0	0.2
	3.6	0.0	82.3	0.0	3.0	0.0	1.3
	5.4	0.0	19.8	0.0	1.1	0.0	0.1
56	0	0.0	894.8	0.0	84.9	0.0	24.6
	1.8	0.0	84.8	0.0	5.5	0.0	0.5
	3.6	0.0	53.3	0.0	4.1	0.0	1.0
	5.4	3.8	70.3	0.6	2.6	0.1	0.3
112	0	0.0	2256.5	0.0	93.5	0.0	18.3
	1.8	0.0	373.0	0.0	28.0	0.0	3.5
	3.6	1.1	317.3	0.2	26.2	0.0	7.5
	5.4	0.0	205.3	0.0	26.1	0.0	3.5

[z]In Year 2, nitrogen affected grass stem and root dry biomass and number of plants ($P<0.009$), and density affected affected grass stem and root biomass and number of plants ($P<0.014$).

Table 3.5. Number of plants and stem and root dry biomass of rushes collected from plots treated with postemergence treatments (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Rushes					
		Plants ($no. \cdot m^{-2}$)		Stem biomass ($g \cdot m^{-2}$)		Root biomass ($g \cdot m^{-2}$)	
		2000	2001	2000	2001	2000	2001
0	0	22.9	27.1	1.5	3.1	0.5	1.1
	1.8	24.9	28.0	1.4	4.4	1.1	5.2
	3.6	0.6	5.8	0.1	1.3	0.1	1.4
	5.4	27.9	12.0	1.8	3.2	0.7	1.2
28	0	55.3	95.6	2.4	10.3	2.2	6.2
	1.8	55.4	189.5	1.5	25.9	1.6	8.2
	3.6	1.5	22.3	0.1	3.6	0.1	1.8
	5.4	12.4	30.5	0.2	5.5	0.3	1.2
56	0	31.6	69.0	1.2	7.9	0.9	4.4
	1.8	16.9	27.1	0.7	4.8	0.5	2.6
	3.6	50.9	30.8	2.6	7.2	1.4	6.8
	5.4	5.9	22.1	0.4	8.5	0.3	1.8
112	0	30.4	99.4	1.3	6.2	0.8	3.1
	1.8	12.3	14.3	0.8	2.2	0.7	0.9
	3.6	19.1	13.4	0.8	1.4	0.8	0.3
	5.4	1.3	21.6	0.1	2.4	0.1	1.3

Table 3.6. Number of plants and stem and root dry biomass of sedge plants collected from plots treated with postemergence treatments (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Sedges					
		Plants ($no. \cdot m^{-2}$)[z]		Stem biomass ($g \cdot m^{-2}$)[y]		Root biomass ($g \cdot m^{-2}$)[x]	
		2000	2001	2000	2001	2000	2001
0	0	14.9	60.8	1.5	5.4	0.6	1.5
	1.8	34.9	27.1	6.2	1.7	1.8	0.3
	3.6	14.9	40.0	2.3	3.8	0.9	0.5
	5.4	16.0	23.1	1.8	2.5	0.7	0.7
28	0	67.1	76.1	6.3	4.3	1.8	1.1
	1.8	18.9	98.6	4.5	12.5	1.4	2.1
	3.6	43.8	100.9	5.6	20.2	1.5	5.9
	5.4	107.6	61.6	14.9	10.0	4.1	1.8
56	0	120.5	363.3	18.3	26.7	12.5	6.3
	1.8	71.5	197.8	15.4	29.3	5.5	5.1
	3.6	43.6	59.6	5.4	11.8	2.1	2.9
	5.4	43.3	56.3	8.2	15.7	2.9	3.5
112	0	34.3	413.6	4.8	37.1	2.1	8.5
	1.8	12.0	260.3	0.9	33.4	0.4	5.9
	3.6	113.8	384.1	19.4	49.9	6.8	4.3
	5.4	79.9	200.4	12.6	34.6	3.5	10.4

[z]Nitrogen affected the number of sedge stems in Year 2 (P=0.034).

[y]Nitrogen and density interacted to affect stem biomass during the first two years (P=0.003).

[x]Nitrogen affected root dry biomass (P=0.037) during the first two years.

Table 3.7. Total above- and belowground biomass of plant types collected from plots treated with postemergence treatments (N=4).

		Plant biomass by type ($g \cdot m^{-2}$)							
Nitrogen	Vine density	Broad-leaved[z]		Grasses[y]		Rushes		Sedges[x]	
($kg \cdot ha^{-1}$)	($t \cdot ha^{-1}$)	2000	2001	2000	2001	2000	2001	2000	2001
0	0	7.6	11.1	4.5	13.9	2.0	4.2	2.1	6.8
	1.8	5.5	4.6	0.2	1.1	2.4	9.7	8.0	2.1
	3.6	1.2	1.9	0.6	0.1	0.0	2.7	3.3	4.3
	5.4	3.5	5.5	0.0	0.5	2.3	4.5	2.5	3.2
28	0	36.4	21.0	0.6	32.0	4.6	16.5	8.1	5.4
	1.8	32.2	10.7	0.0	2.0	3.1	34.2	5.9	14.7
	3.6	19.1	9.3	0.0	4.3	0.1	5.4	7.0	26.1
	5.4	13.6	6.4	0.0	1.2	0.5	6.6	19.0	11.8
56	0	38.6	43.0	0.0	109.5	2.1	12.4	30.8	33.0
	1.8	19.0	9.5	0.0	6.0	1.2	7.4	20.9	34.4
	3.6	14.9	7.8	0.0	5.1	4.1	14.0	7.5	14.7
	5.4	31.4	11.9	0.7	2.9	0.7	10.3	11.1	19.2
112	0	14.2	60.3	0.0	111.8	2.0	9.3	6.9	45.5
	1.8	14.1	14.2	0.0	31.5	1.5	3.1	1.3	39.3
	3.6	10.9	8.0	0.2	33.8	1.6	1.7	26.2	54.2
	5.4	11.6	11.4	0.0	29.6	0.0	3.7	16.1	45.0

[z]Density affected total BL biomass during the first two years ($P=0.024$) and nitrogen affected total BL biomass in Year 2 ($P=0.028$).

[y]Density and nitrogen affected total grass biomass in Year 2 ($P \leq 0.001$).

[x]Nitrogen affected total sedge biomass in Year 2 ($P=0.011$) and N*D affected total sedge biomass during the first two years ($P=0.011$).

Table 3.8. Total number of plants and total biomass of all noncranberry plants collected from plots treated with postemergence treatments (N=4).

		Total plant measurements					
Nitrogen	Vine density	Plants (no.•m^{-2})		Stem biomass (g•m^{-2})		Root biomass (g•m^{-2})	
(kg•ha^{-1})	(t•ha^{-1})	2000	2001	2000	2001	2000	2001
0	0	90.0	331.9	12.4	27.8	3.9	8.3
	1.8	72.0	106.0	12.5	10.5	3.7	7.0
	3.6	22.9	58.4	3.8	6.6	1.4	2.5
	5.4	61.0	77.9	6.3	9.9	2.0	3.6
28	0	154.1	846.8	35.8	59.1	13.9	15.9
	1.8	128.9	384.0	32.5	48.7	8.7	12.9
	3.6	68.1	251.1	20.4	33.8	5.8	11.3
	5.4	188.0	165.1	26.5	22.0	6.7	4.1
56	0	196.3	1577.3	43.2	154.4	28.3	43.4
	1.8	113.9	379.3	32.7	47.1	8.4	10.1
	3.6	121.1	160.9	18.5	28.3	8.0	13.4
	5.4	142.0	176.1	35.9	35.5	8.1	8.8
112	0	93.4	3335.0	17.3	184.1	5.9	42.8
	1.8	36.1	1027.4	13.6	75.8	3.2	12.3
	3.6	174.0	751.6	28.4	84.6	10.5	13.1
	5.4	109.3	511.3	23.1	70.9	4.7	18.9

[z]Nitrogen and density affected total number of shoots in Year 2 ($P \leq 0.001$).

[y]Nitrogen and density affected total root weight during the first two years ($P \leq 0.015$).

[x]N*D affected total stem weight in Year 2 ($P=0.033$).

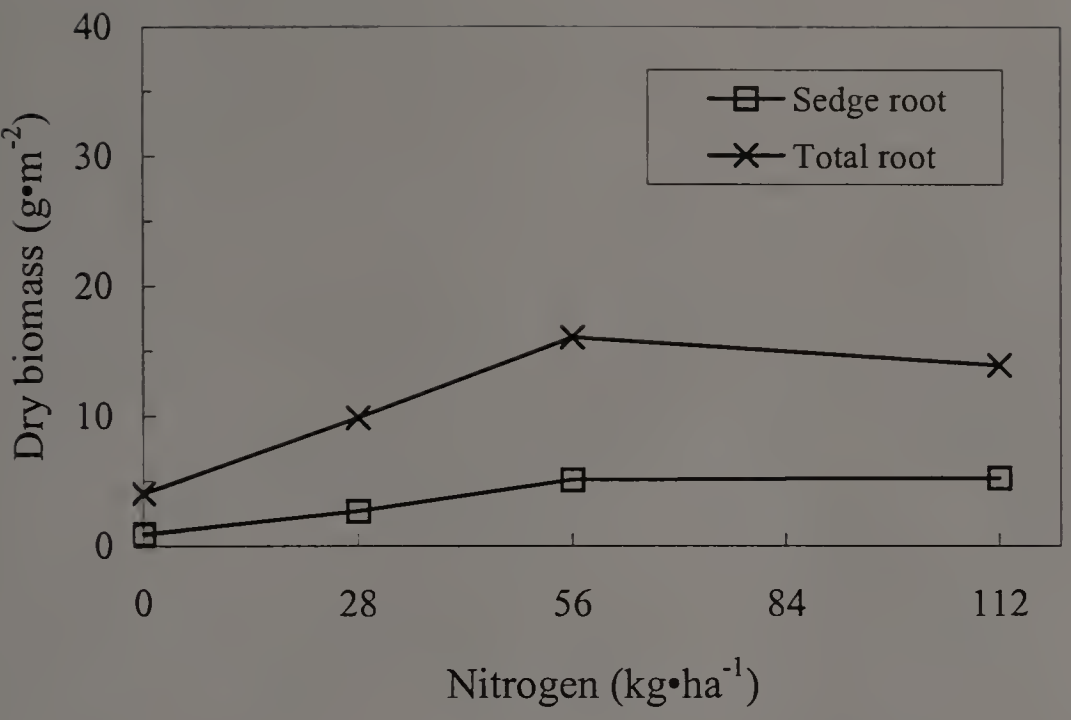

Figure 3.4. Effect of nitrogen rate on sedge root and total root biomass collected during the first two years of growth from plots treated postemergence (N=32).

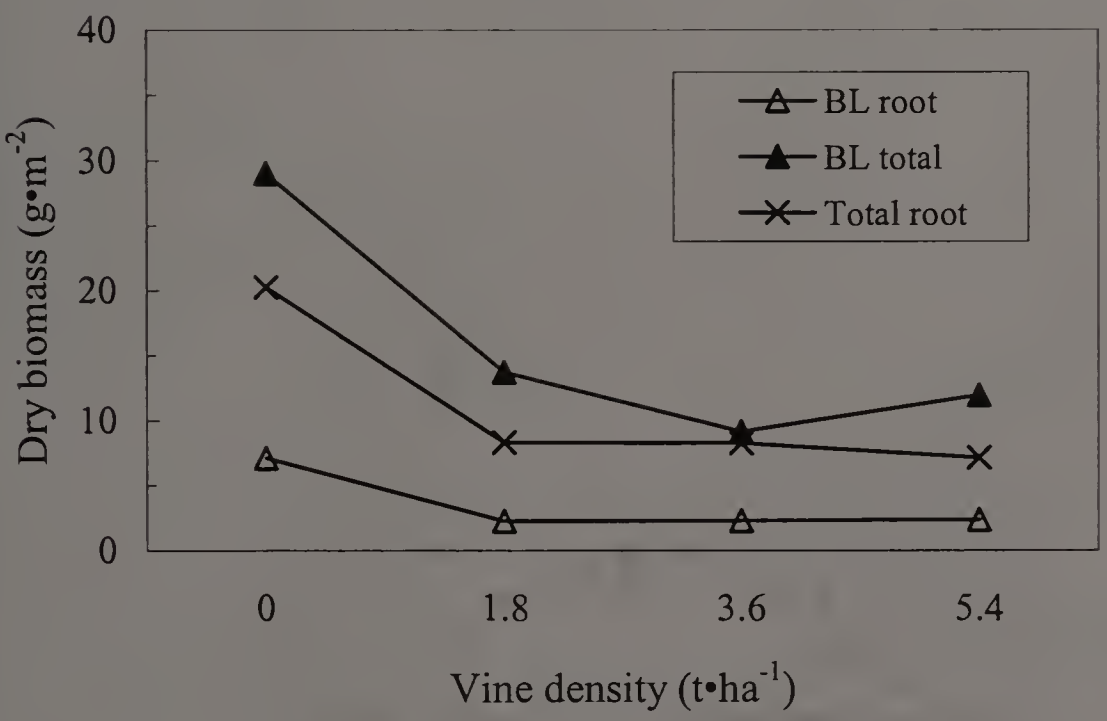

Figure 3.5. Effect of vine density on BL root, BL total, and total root biomass collected during the first two years of growth from plots treated postemergence (N=32).

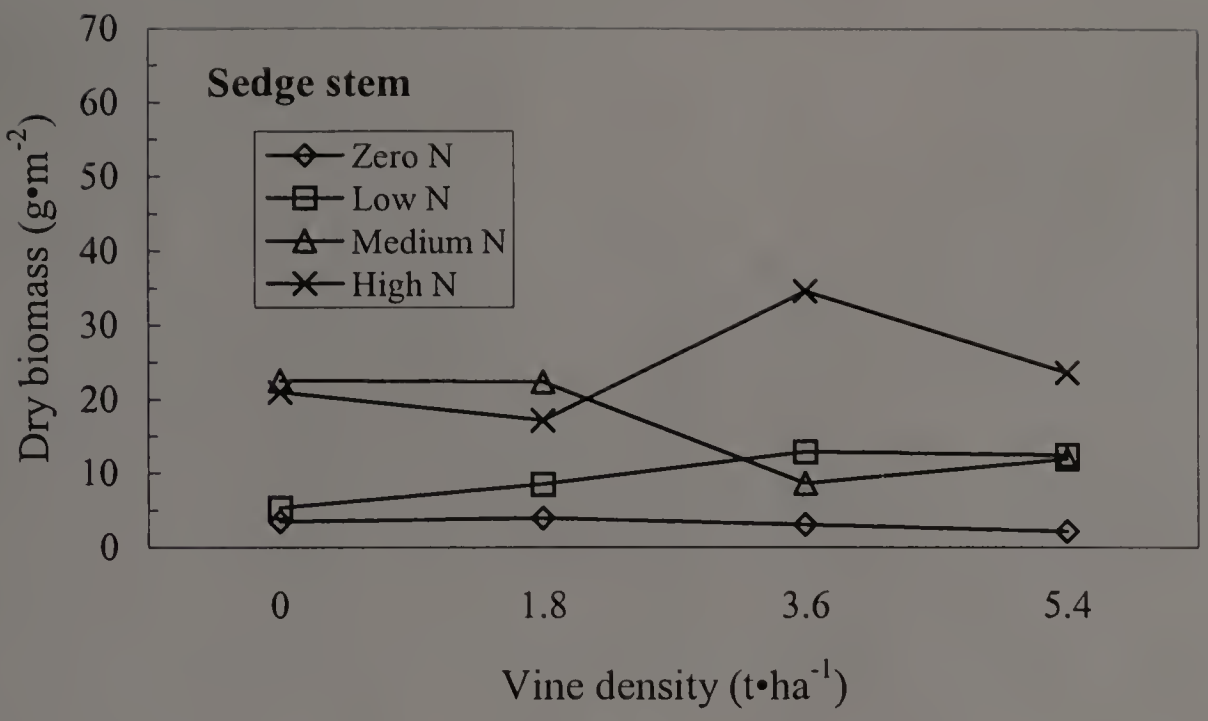

Figure 3.6. Interaction of nitrogen rate and vine density on sedge stem biomass collected during the first two years of growth from plots treated postemergence (N=32). Significant differences among densities occurred at medium and high N rates.

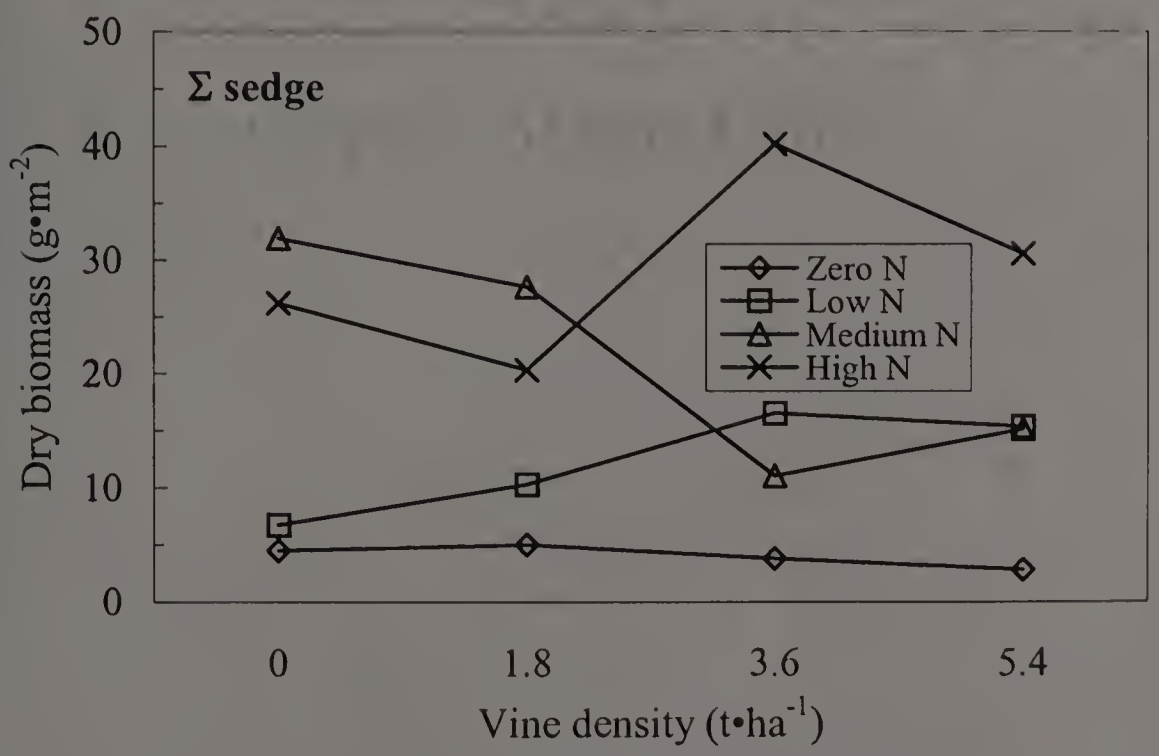

Figure 3.7. Interaction of nitrogen rate and vine density on total sedge biomass during the first two years from plots treated postemergence (N=32). Significant differences among densities occurred at medium and high N rates.

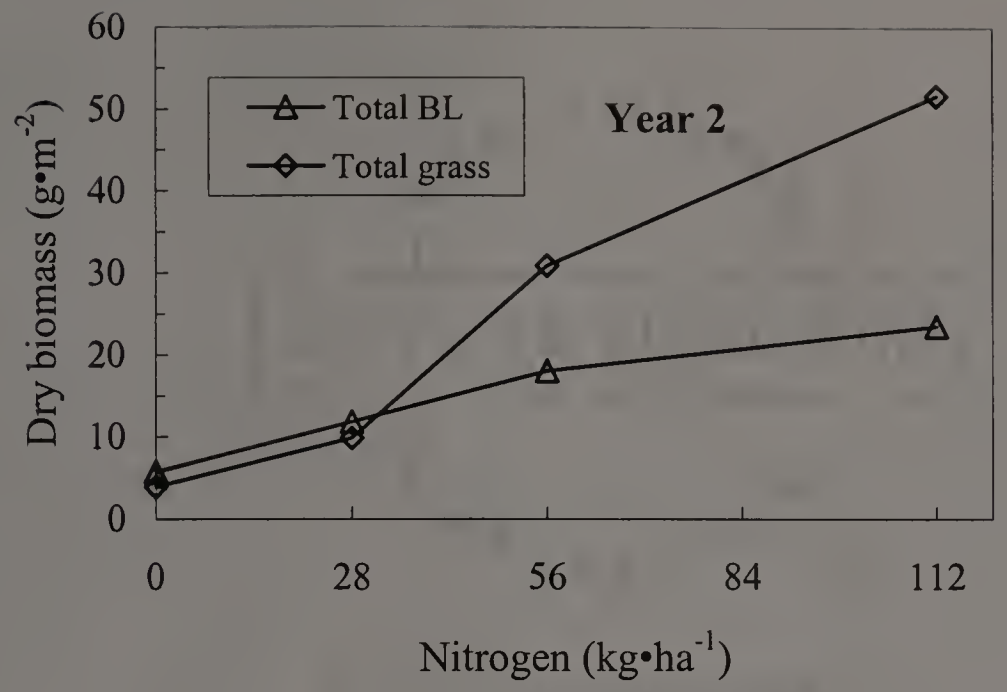

Figure 3.8. Effect of nitrogen rate on total biomass of various plant groups collected in Year 2 from plots treated postemergence (N=16).

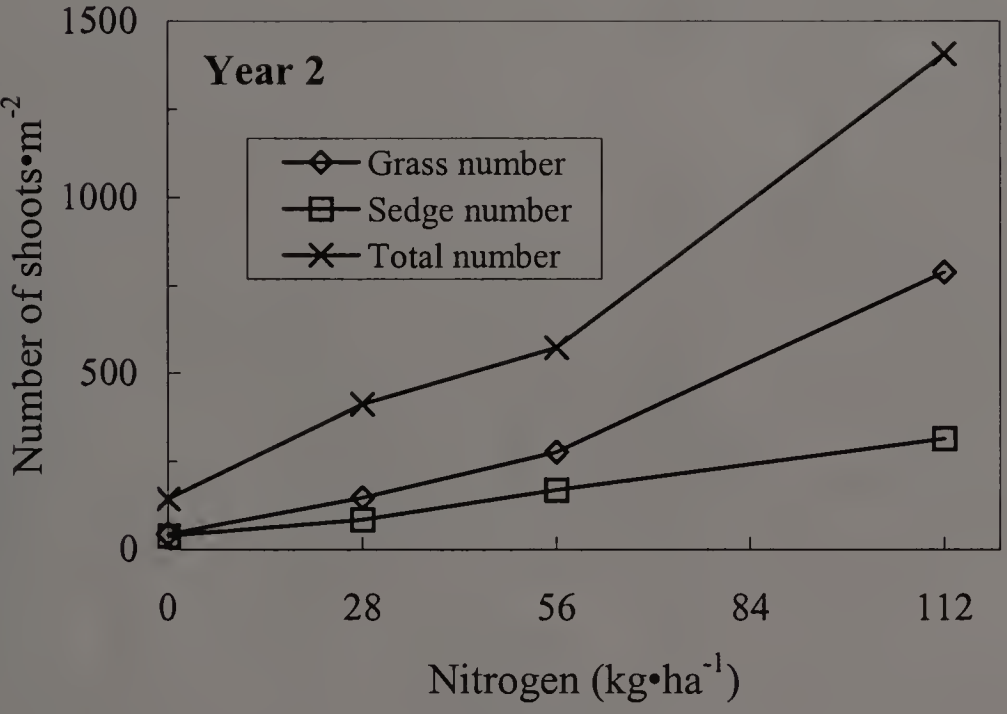

Figure 3.9. Effect of nitrogen rate on the number of shoots of various plants groups collected in Year 2 from plots treated postemergence (N=16).

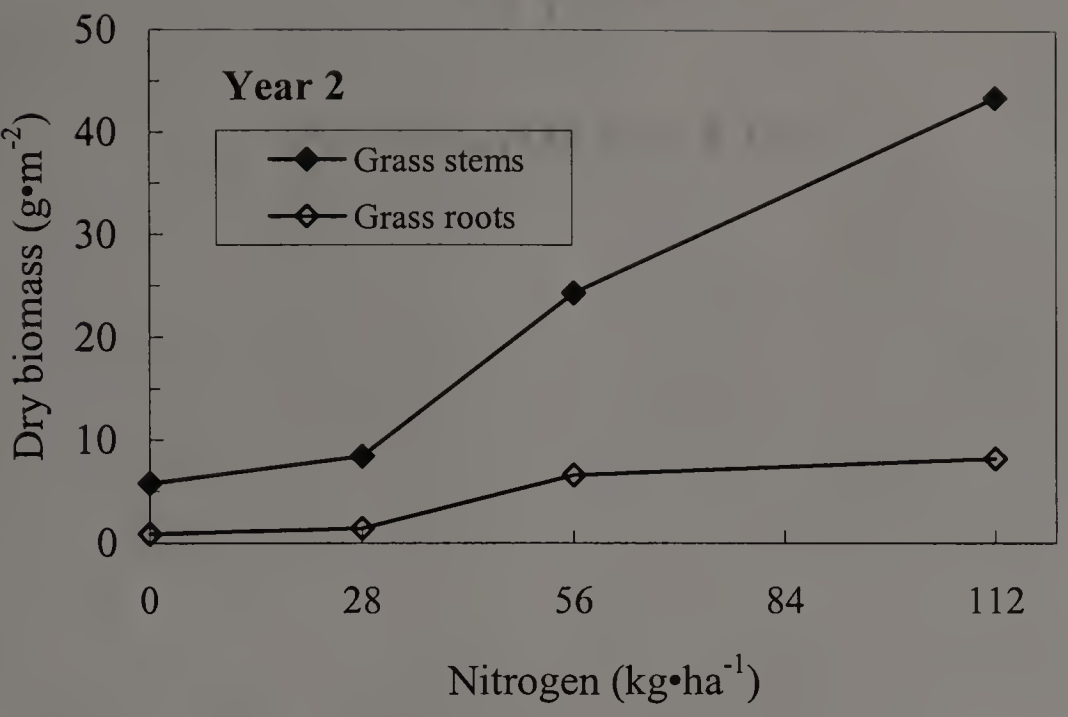

Figure 3.10. Effect of nitrogen rate on grass stem and root dry biomass collected in Year 2 from plots treated postemergence (N=16).

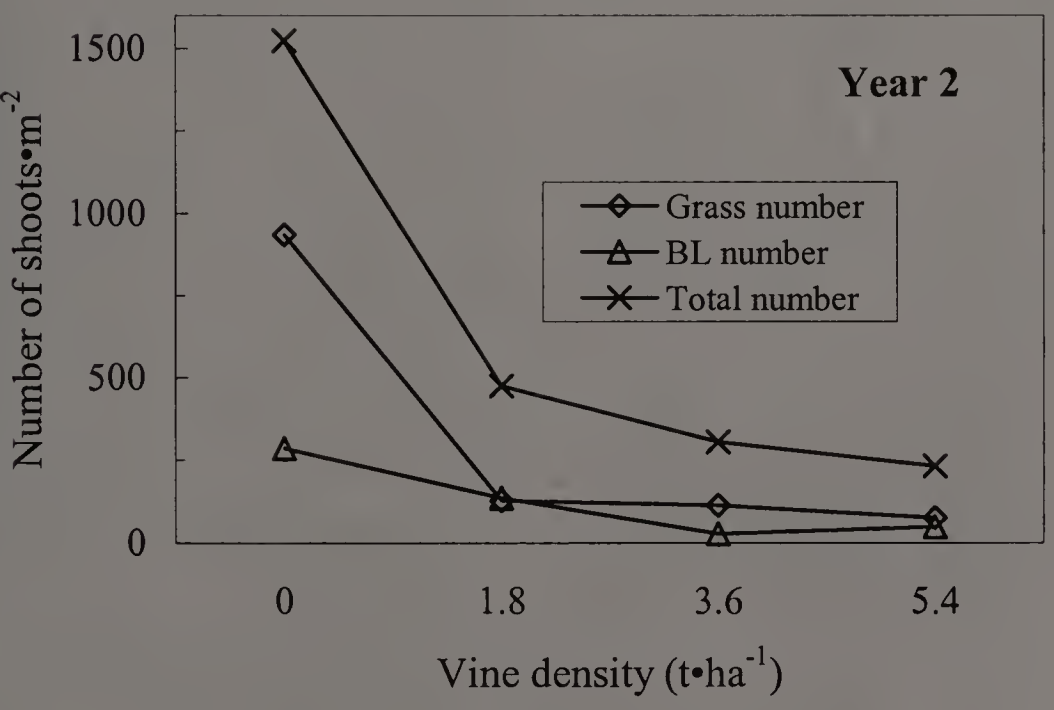

Figure 3.11. Effect of vine density on the number of shoots of various plants groups collected in Year 2 from plots treated postemergence (N=16).

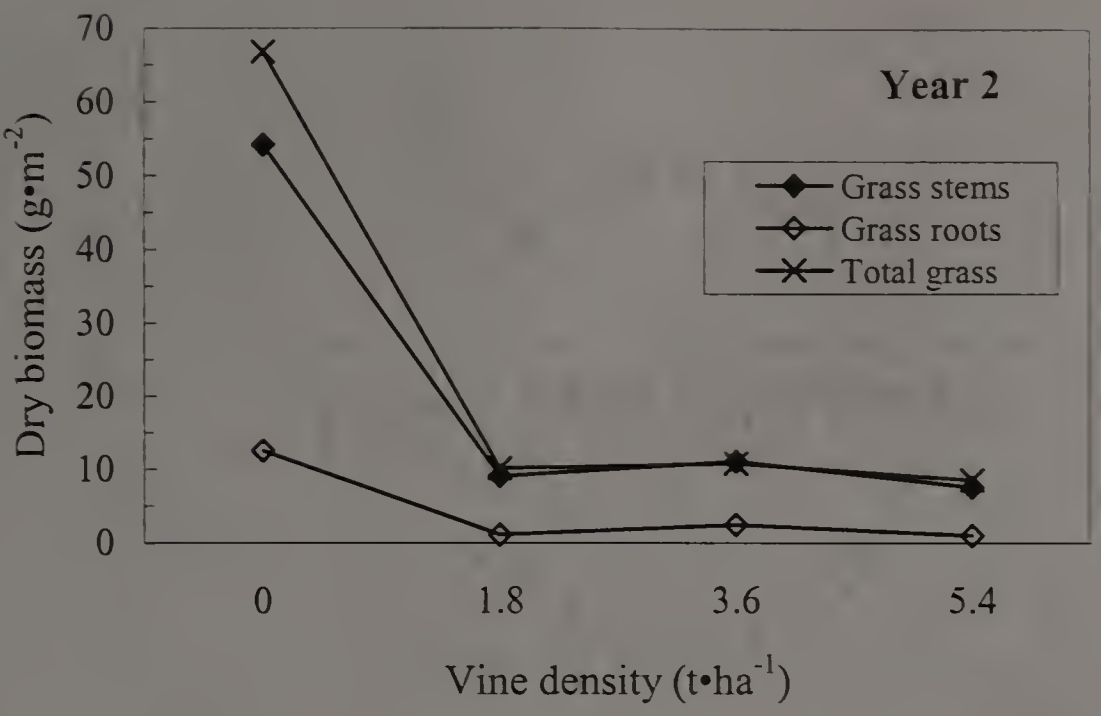

Figure 3.12. Effect of vine density on grass stem, root, and total biomass collected in Year 2 from plots treated postemergence (N=16).

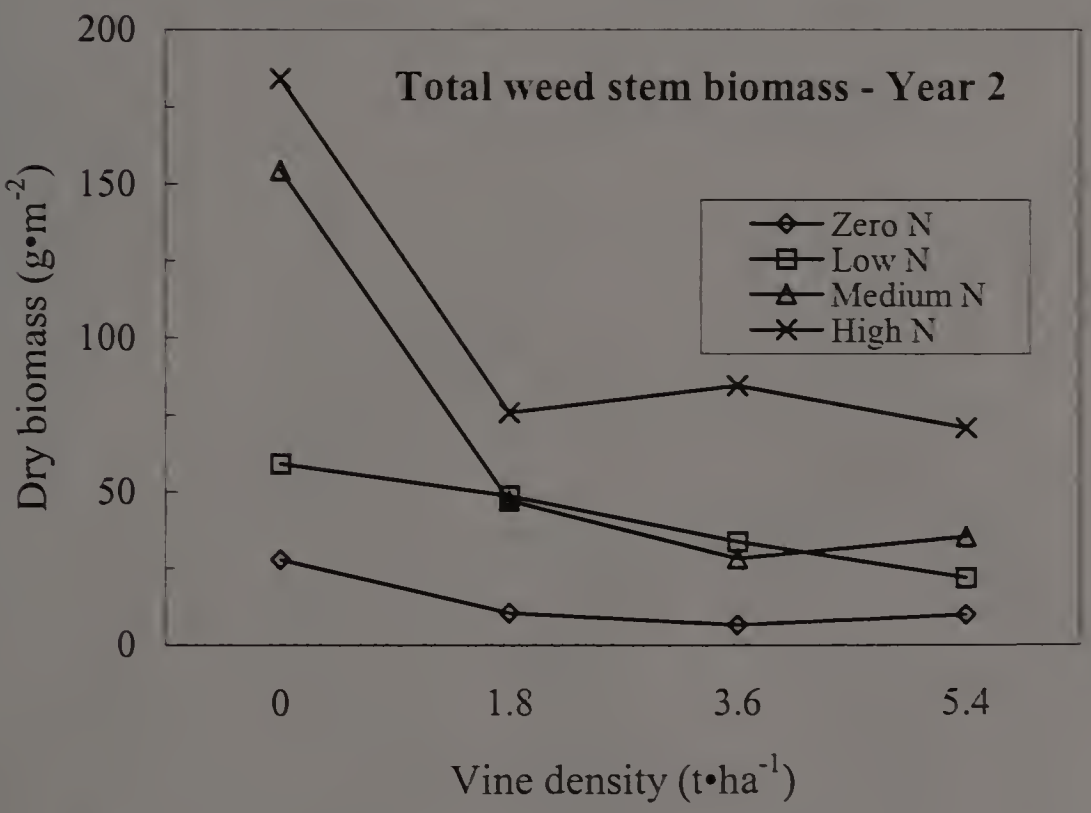

Figure 3.13. Interaction of nitrogen rate and vine density on total stem biomass of weeds collected in Year 2 from plots treated postemergence (N=16).
Significant differences among densities occurred at low, medium, and high N rates.

Table 3.9. Time needed to remove all noncranberry plants from plots receiving postemergence treatments (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Time ($min \cdot m^{-2}$)[z]	
		2000	2001
0	0	1.4	5.8
	1.8	1.5	3.3
	3.6	1.0	2.3
	5.4	1.7	2.9
28	0	1.8	7.3
	1.8	2.3	8.9
	3.6	1.8	4.2
	5.4	3.2	3.8
56	0	2.7	9.6
	1.8	3.7	10.8
	3.6	2.0	6.3
	5.4	5.4	7.3
112	0	1.3	10.1
	1.8	1.1	6.0
	3.6	4.2	23.0
	5.4	2.4	12.7

[z]N*D affected weeding time in Year 1 ($P=0.022$) and Year 2 ($P<0.001$).

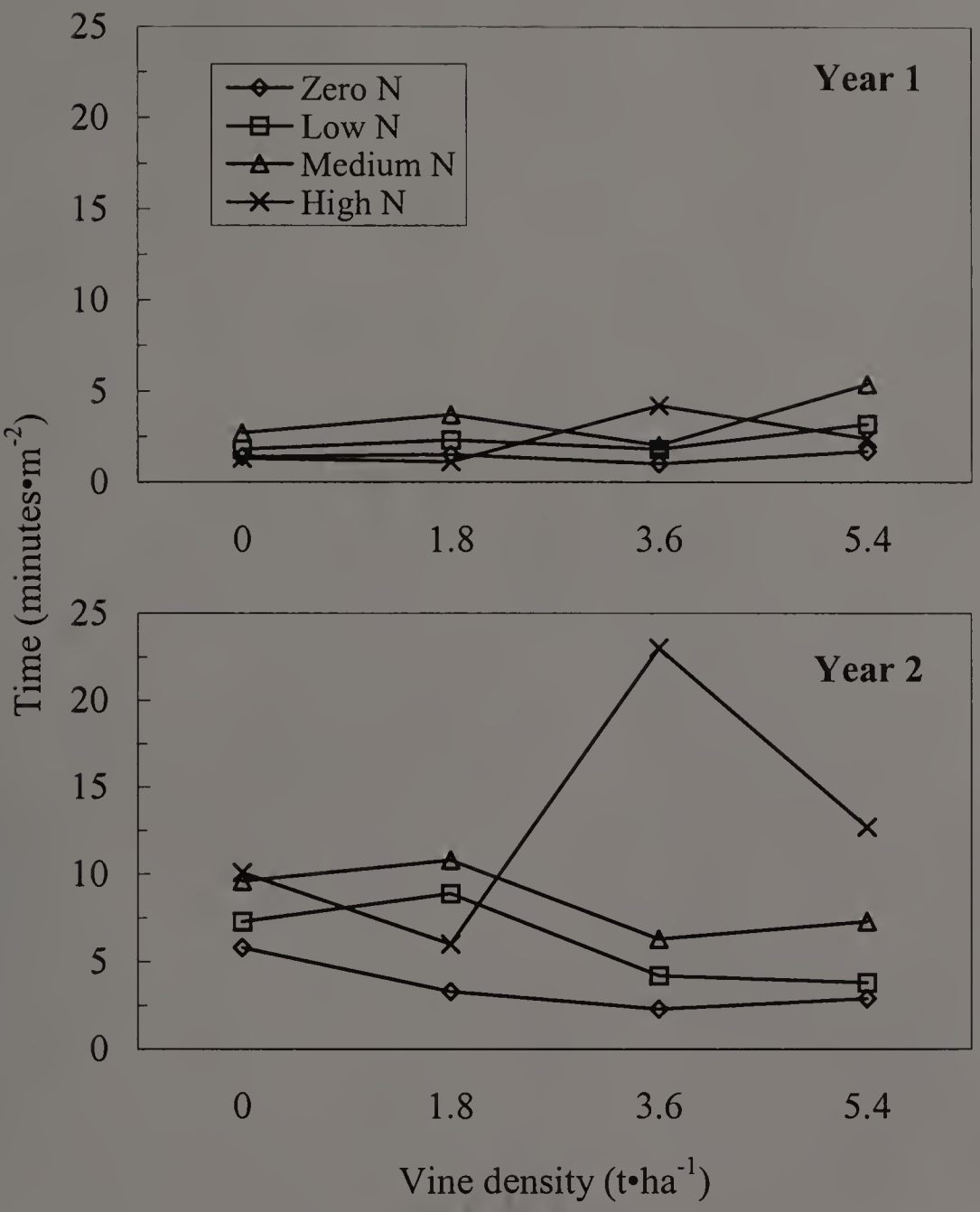

Figure 3.14. Interaction of nitrogen rate and vine density in Year 1 and Year 2 on the time needed to remove weeds from plots treated postemergence (N=4). Significant differences among densities occurred at medium and high N rates for Year 1 and at low and high N rates for Year 2.

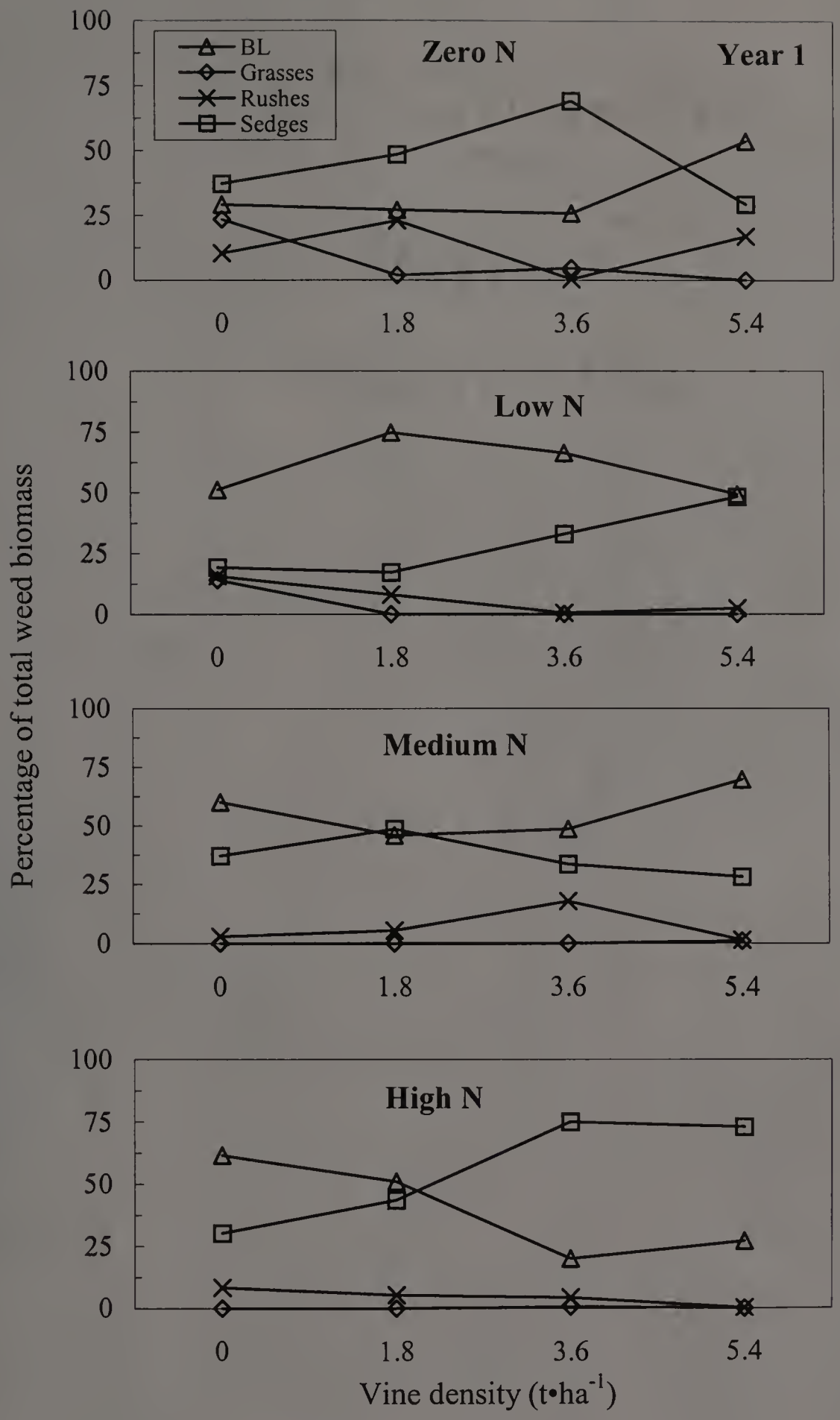

Figure 3.15. Mean percentage of each plant group of total weed biomass produced in the postemergence WMO plots in Year 1 (N=4).

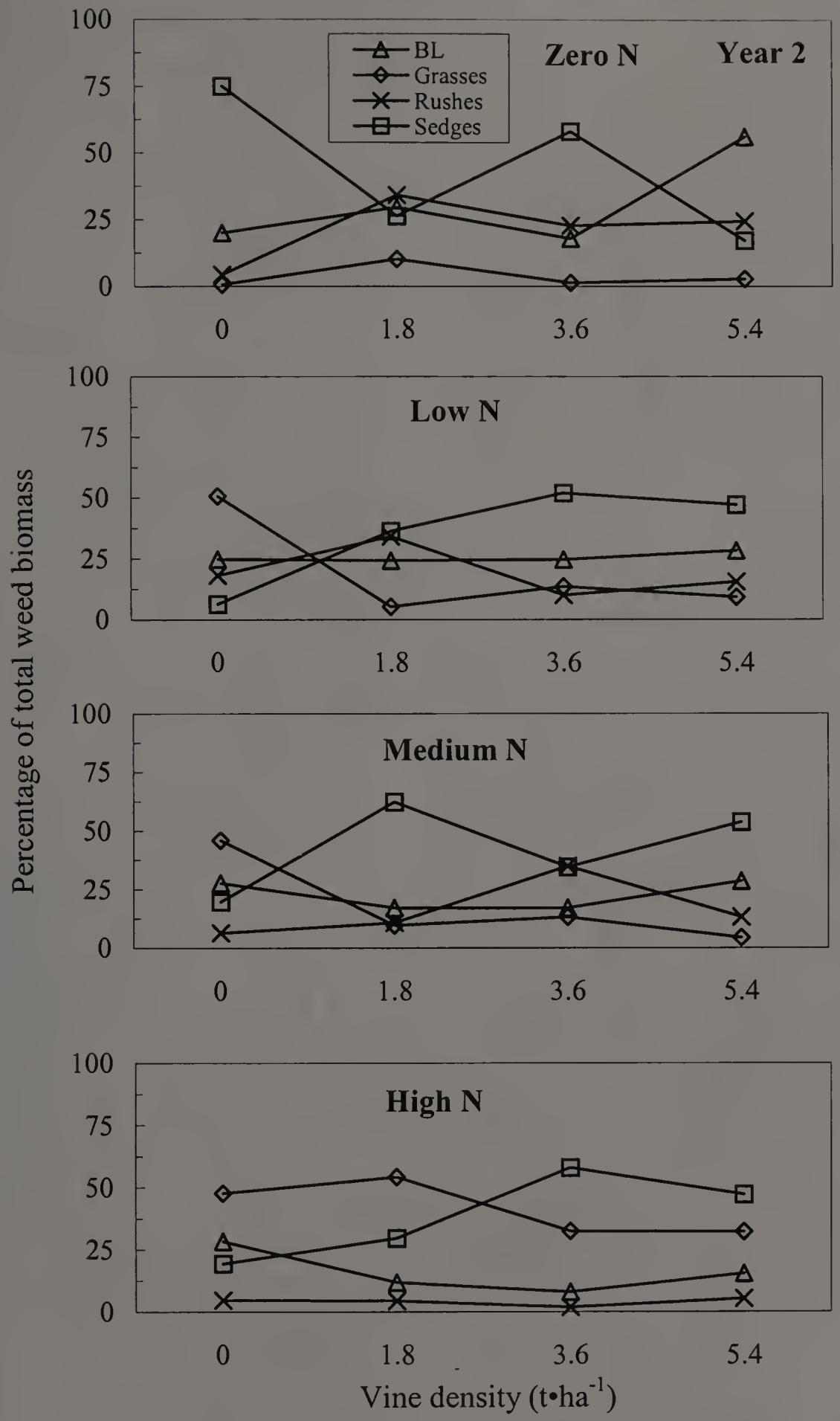

Figure 3.16. Mean percentage of each plant group of total weed biomass produced in the postemergence WMO plots in Year 2 (N=4).

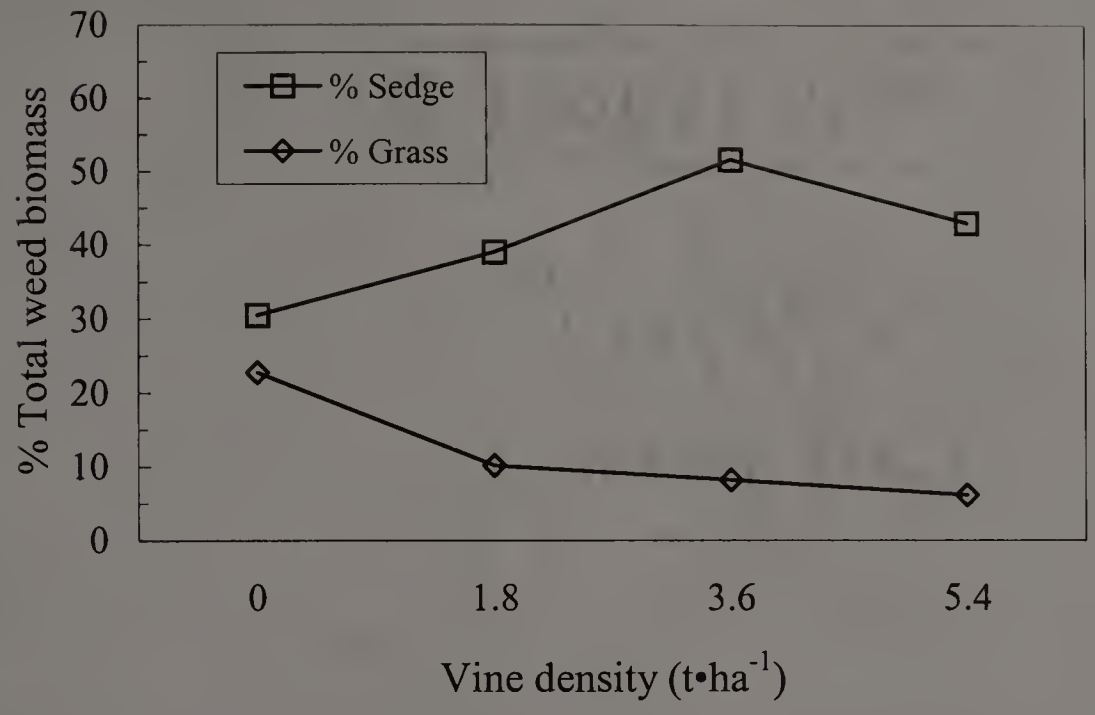

Figure 3.17. Effect of vine density on mean percentage sedge and grass of total weed biomass from postemergence WMO in the first two years (N=32).

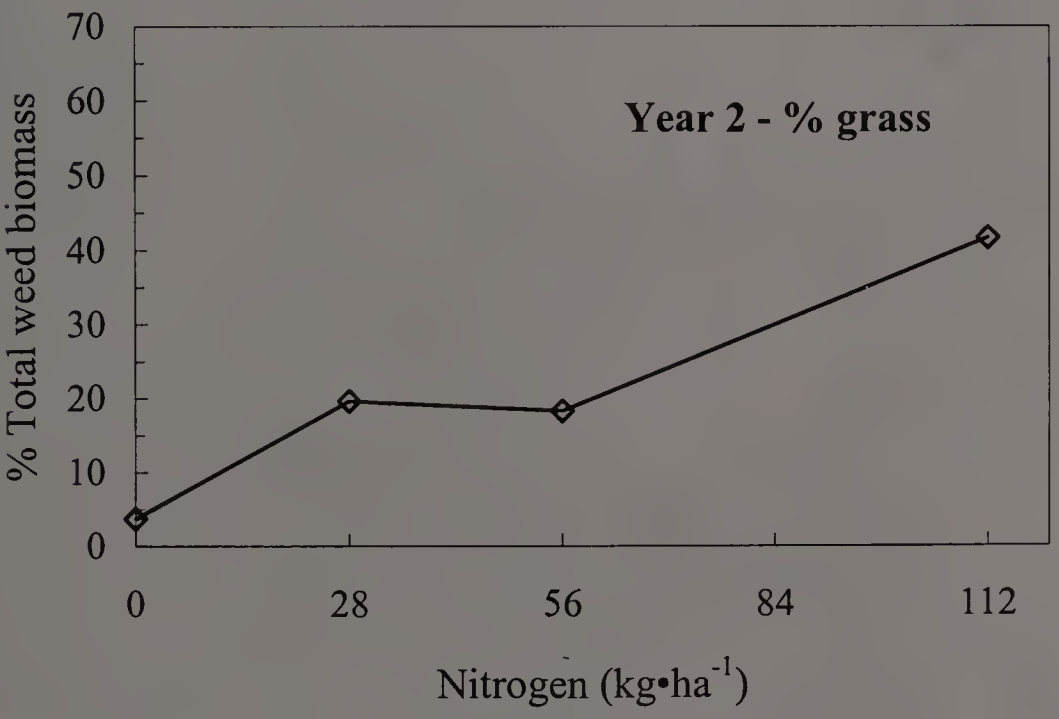

Figure 3.18. Effect of nitrogen rate on mean percentage grass of total weed biomass from postemergence WMO in Year 2 (N=16).

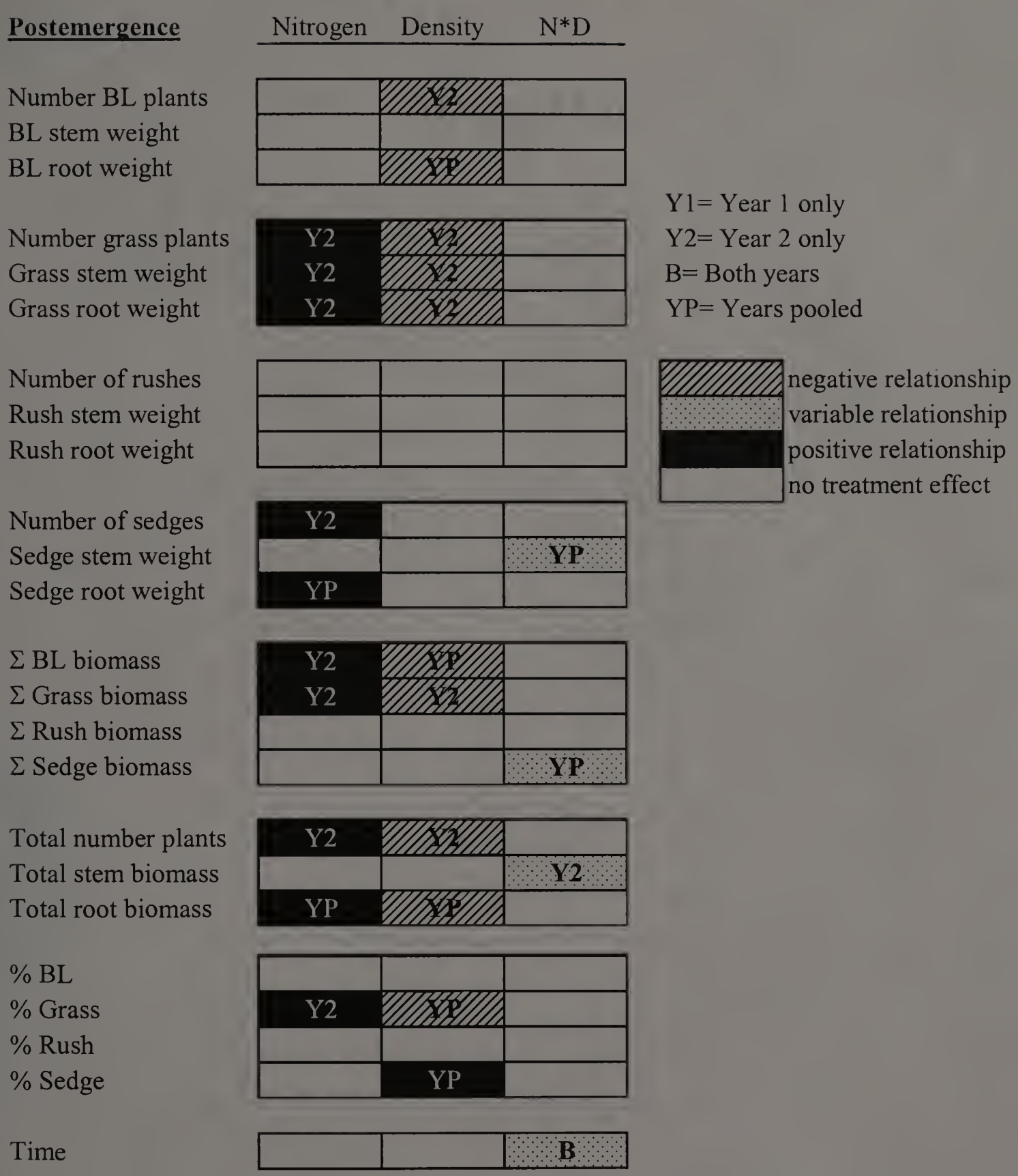

Figure 3.19. Summary of the general trends of nitrogen rate and vine density for postemergence treatments.

Table 3.10. Dry biomass of cranberry plants collected from all weed management option plots (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Cranberry dry biomass ($g \cdot m^{-2}$)					
			Stem[z]		Root[y]		Total[x]	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
0	0	Pre	0.7	0.0	0.0	0.0	0.7	0.0
		Post	0.0	0.5	0.0	0.0	0.0	0.5
		Inoc	0.0	0.0	0.0	0.0	0.0	0.0
		Unt	0.4	0.0	0.1	0.0	0.5	0.0
	1.8	Pre	95.3	151.2	31.0	33.8	126.3	185.0
		Post	91.4	174.2	26.9	26.9	118.3	201.1
		Inoc	80.2	131.4	26.9	13.6	107.1	145.0
		Unt	55.3	152.8	15.4	30.6	70.7	183.4
	3.6	Pre	157.1	192.9	60.6	38.8	217.7	231.7
		Post	131.6	230.0	33.8	38.0	165.4	268.0
		Inoc	126.6	249.9	59.1	55.5	185.7	305.4
		Unt	122.7	220.7	27.2	24.0	150.0	244.7
	5.4	Pre	181.8	286.3	51.6	37.7	233.3	324.0
		Post	143.2	285.0	57.9	48.8	201.0	333.8
		Inoc	154.8	255.8	53.8	25.8	208.6	281.5
		Unt	184.1	328.9	73.4	61.6	257.5	390.5
28	0	Pre	0.0	0.1	0.0	0.0	0.0	0.1
		Post	0.0	0.0	0.0	0.0	0.0	0.0
		Inoc	0.0	0.0	0.0	0.0	0.0	0.0
		Unt	0.0	0.1	0.0	0.0	0.0	0.1
	1.8	Pre	118.9	316.9	61.0	50.9	180.0	367.8
		Post	125.5	307.5	45.1	23.6	170.6	331.1
		Inoc	104.1	244.9	44.8	19.5	148.9	264.4
		Unt	74.7	226.5	15.9	18.2	90.6	244.7
	3.6	Pre	152.2	634.7	69.2	36.9	221.4	671.6
		Post	179.7	456.0	104.8	37.7	284.5	493.7
		Inoc	136.8	373.5	62.9	54.4	199.7	427.9
		Unt	125.4	393.7	59.2	95.7	184.6	489.4
	5.4	Pre	298.6	550.9	119.9	74.5	418.5	625.4
		Post	272.6	543.5	114.0	88.3	386.5	631.8
		Inoc	168.7	528.3	31.6	21.1	200.3	549.4
		Unt	183.1	459.9	88.5	91.5	271.6	551.4

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Table 3.10, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Cranberry dry biomass ($g \cdot m^{-2}$) Stem Year 1	Stem Year 2	Root Year 1	Root Year 2	Total Year 1	Total Year 2
56	0	Pre	0.0	12.1	0.0	1.1	0.0	13.2
		Post	0.0	0.9	0.0	0.0	0.0	0.9
		Inoc	0.4	0.0	0.1	0.0	0.5	0.0
		Unt	0.2	17.1	0.0	0.0	0.2	17.1
	1.8	Pre	138.0	650.0	47.9	102.1	185.9	752.1
		Post	135.8	591.7	49.4	69.3	185.3	661.0
		Inoc	117.2	327.3	34.1	22.9	151.3	350.2
		Unt	85.3	433.6	19.6	64.5	104.8	498.1
	3.6	Pre	192.4	741.5	44.2	122.5	236.6	864.0
		Post	291.8	726.2	162.8	78.7	454.6	804.9
		Inoc	180.9	446.6	55.4	58.0	236.4	504.6
		Unt	212.6	516.0	114.3	29.7	326.9	545.7
	5.4	Pre	226.0	769.5	56.2	50.4	282.2	819.9
		Post	250.2	711.9	122.0	46.0	372.1	757.9
		Inoc	152.5	534.3	25.7	72.6	178.3	606.9
		Unt	235.0	596.7	97.7	168.5	332.7	765.2
112	0	Pre	0.0	0.0	0.0	0.0	0.0	0.0
		Post	0.8	0.0	0.3	0.4	1.1	0.4
		Inoc	0.0	3.1	0.0	0.2	0.0	3.3
		Unt	0.0	0.0	0.0	0.0	0.0	0.0
	1.8	Pre	201.7	612.3	84.5	86.9	286.2	699.2
		Post	145.5	555.1	64.8	28.1	210.4	583.2
		Inoc	103.2	341.4	32.9	9.1	136.1	350.5
		Unt	128.5	562.4	46.0	32.7	174.5	595.1
	3.6	Pre	237.0	830.6	76.5	173.7	313.6	1004.3
		Post	203.2	844.2	82.5	74.0	285.7	918.2
		Inoc	119.5	495.6	34.9	53.1	154.4	548.7
		Unt	201.0	678.1	42.7	119.0	243.7	797.1
	5.4	Pre	264.5	900.3	93.1	119.5	357.6	1019.8
		Post	236.8	890.6	76.3	70.4	313.1	961.0
		Inoc	218.9	648.0	62.9	44.2	281.8	692.2
		Unt	186.1	612.9	57.8	91.6	243.9	704.5

[z]WMO affected stem biomass (P=0.003) for the first two years. Year 1: Nitrogen*density affected stem biomass (P=0.012). Year 2: N*D affected stem biomass (P<0.001).
[y]The effect of WMO on root biomass varied by density (P=0.041).
[x]Year 1: Total biomass was affected by density (P<0.001) and N*D (P=0.054). Year 2: N*D affected total biomass (P<0.001).

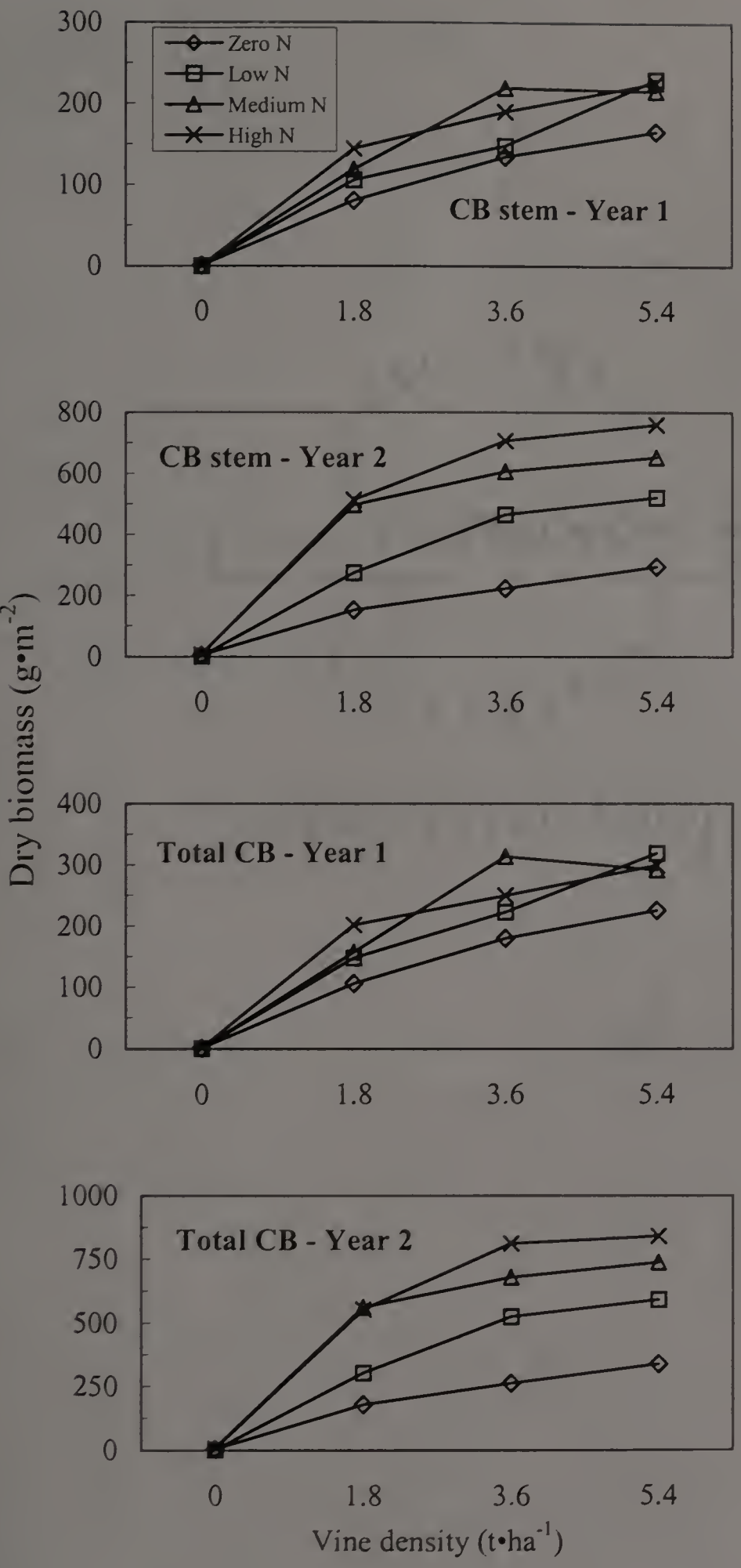

Figure 3.20. Interaction of nitrogen rate and vine density on cranberry stem and total cranberry biomass production, Years 1 and 2 (N=16). Significant differences among densities occurred at all N rates for all parameters in both years.

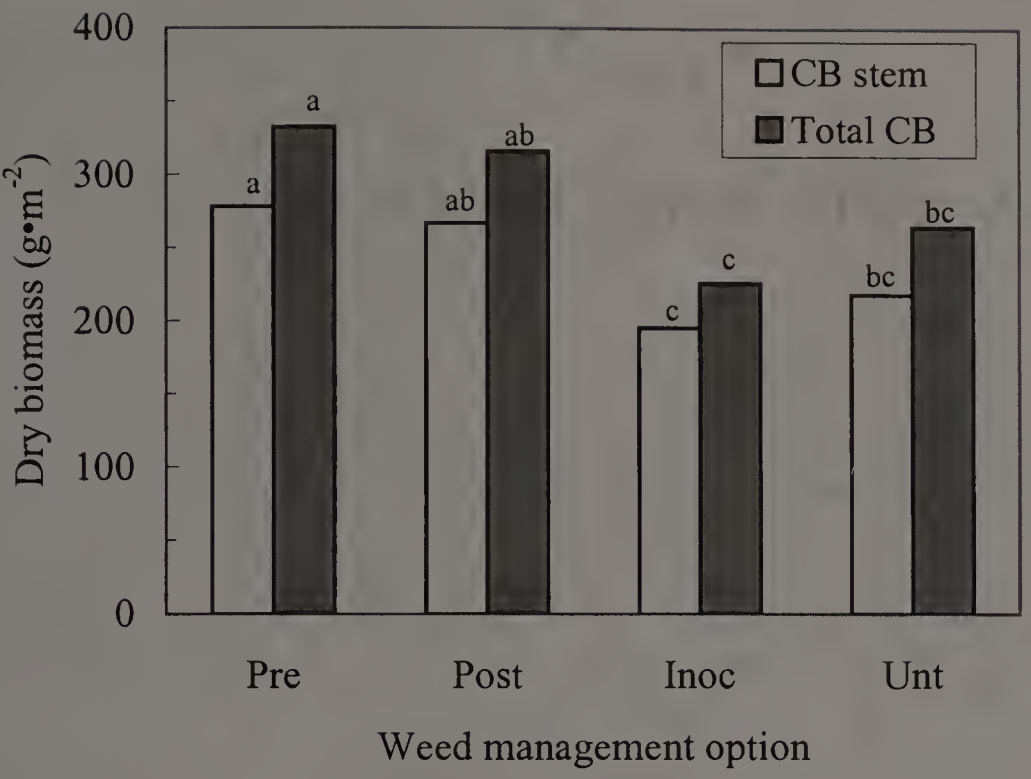

Figure 3.21. Effect of weed management option on cranberry stem and total cranberry biomass production for the first two years (N=128). For each variable, means with similar letters are not significantly different according to Kramer-adjusted Tukey's HSD (P=0.05).

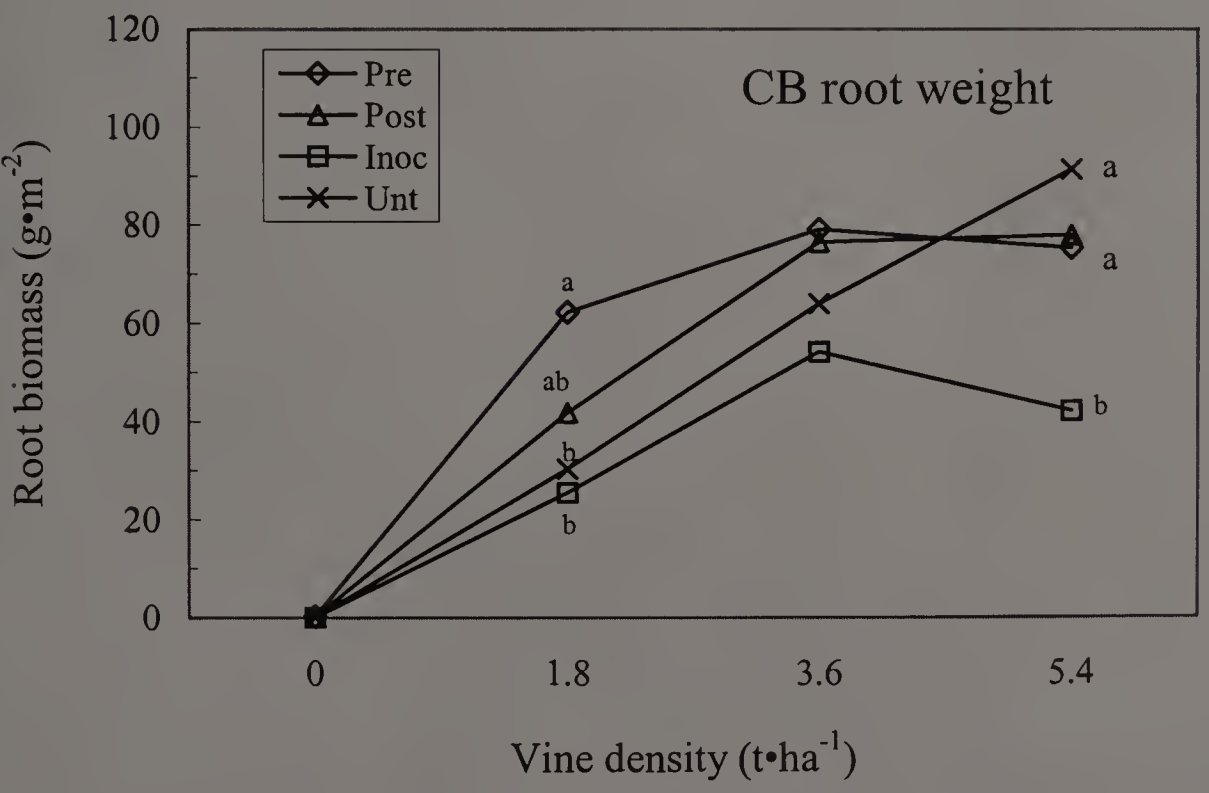

Figure 3.22. Interaction of vine density and weed management option on cranberry root biomass during the first two years of growth (N=32). Significant differences among WMO occurred at low and high densities. Within these densities, means with similar letters are not signficantly different by t-test using Bonferroni-adjusted p-values (P=0.008).

Table 3.11. Dry biomass of weeds collected from all weed management option plots (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Weed dry biomass ($g \cdot m^{-2}$)					
			Stem[z]		Root[y]		Total[x]	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
0	0	Pre	11.2	29.2	1.5	7.5	12.7	36.7
		Post	12.3	37.7	7.6	10.1	19.8	47.8
		Inoc	70.2	56.8	14.5	34.5	84.7	91.3
		Unt	151.6	120.4	37.2	46.2	188.8	166.7
	1.8	Pre	12.0	8.9	0.5	6.4	12.5	15.3
		Post	3.7	3.8	0.4	6.0	4.1	9.8
		Inoc	78.5	20.0	12.3	6.9	90.7	26.9
		Unt	66.6	29.4	28.8	18.6	95.5	48.1
	3.6	Pre	2.9	5.7	0.5	2.7	3.4	8.4
		Post	1.7	2.7	0.9	0.8	2.6	3.5
		Inoc	74.9	35.5	23.4	35.3	98.4	70.8
		Unt	139.8	64.6	32.6	51.8	172.4	116.5
	5.4	Pre	21.9	14.3	19.6	6.7	41.4	21.0
		Post	6.1	4.0	1.5	2.9	7.6	6.9
		Inoc	54.0	62.5	15.9	52.6	70.0	115.1
		Unt	169.8	62.6	49.2	39.2	218.9	101.8
28	0	Pre	96.4	88.0	10.8	34.0	107.2	122.0
		Post	12.1	15.7	7.1	15.4	19.2	31.1
		Inoc	368.4	292.6	86.9	247.4	455.2	540.0
		Unt	333.4	267.9	155.2	156.6	488.6	424.5
	1.8	Pre	32.8	61.1	15.2	29.4	48.0	90.5
		Post	57.7	15.3	31.2	26.6	88.9	41.9
		Inoc	224.4	181.1	70.1	186.2	294.5	367.3
		Unt	304.8	191.2	96.3	250.1	401.2	441.2
	3.6	Pre	87.3	51.4	25.7	21.0	113.0	72.4
		Post	25.0	10.4	1.5	6.1	26.5	16.5
		Inoc	191.1	195.7	53.8	187.8	244.9	383.4
		Unt	285.9	143.0	98.0	75.2	383.9	218.2
	5.4	Pre	27.0	29.1	5.4	10.1	32.4	39.2
		Post	43.2	3.8	45.0	2.9	88.2	6.7
		Inoc	305.2	191.3	140.5	166.4	445.6	357.7
		Unt	170.3	215.8	62.3	134.7	232.6	350.5

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Table 3.11, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Weed dry biomass ($g \cdot m^{-2}$)					
			Stem		Root		Total	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
56	0	Pre	153.1	292.4	42.8	165.8	195.9	458.2
		Post	25.2	34.2	33.7	37.7	58.9	71.8
		Inoc	412.2	360.5	132.1	332.5	544.2	693.1
		Unt	317.1	321.3	156.6	242.5	473.7	563.8
	1.8	Pre	68.7	44.8	16.4	20.1	85.0	64.9
		Post	6.4	32.8	2.0	44.3	8.4	77.0
		Inoc	312.6	251.1	130.7	147.7	443.3	398.8
		Unt	436.0	284.5	202.0	141.1	638.0	425.6
	3.6	Pre	36.5	35.5	7.3	19.4	43.8	54.9
		Post	5.4	9.5	2.8	20.1	8.2	29.6
		Inoc	265.0	323.4	129.3	225.1	394.3	548.5
		Unt	259.8	284.2	95.3	137.4	355.1	421.6
	5.4	Pre	145.0	52.8	32.0	35.3	177.0	88.1
		Post	24.8	9.2	10.8	39.4	35.5	48.6
		Inoc	411.3	328.3	207.4	184.1	618.7	512.4
		Unt	357.6	321.8	287.3	147.7	644.9	469.5
112	0	Pre	41.1	255.3	10.0	140.7	51.1	396.0
		Post	18.9	30.7	8.8	14.6	27.6	45.3
		Inoc	584.1	413.9	195.9	310.6	780.0	724.5
		Unt	712.3	881.4	211.4	582.2	923.7	1463.6
	1.8	Pre	116.8	150.7	11.9	116.1	128.7	266.8
		Post	11.0	44.1	3.6	20.0	14.5	64.1
		Inoc	483.7	443.5	223.5	242.4	707.2	686.0
		Unt	329.8	488.3	90.2	152.5	420.0	640.8
	3.6	Pre	27.1	104.3	3.4	121.4	30.5	225.7
		Post	22.1	26.9	7.5	31.3	29.6	58.2
		Inoc	410.1	410.0	161.4	375.6	571.5	785.6
		Unt	266.7	340.1	35.7	238.9	302.5	579.0
	5.4	Pre	70.4	113.4	27.8	26.8	98.2	140.2
		Post	20.1	23.5	11.6	6.4	31.8	30.0
		Inoc	422.0	351.8	157.6	142.6	579.5	494.4
		Unt	546.3	273.6	286.5	143.6	832.8	417.1

[z]N*W and N*D*W affected stem biomass ($P<0.001$ and $P=0.043$, respectively) for the first two years.

[y]Density affected weed root biomass in Year 1 ($P=0.008$) and in Year 2 ($P=0.016$).
N*W affected root biomass ($P<0.001$) for the first two years.

[x]N*W and N*D*W affected total biomass ($P=0.001$ and $P=0.041$, respectively) for the first two years.

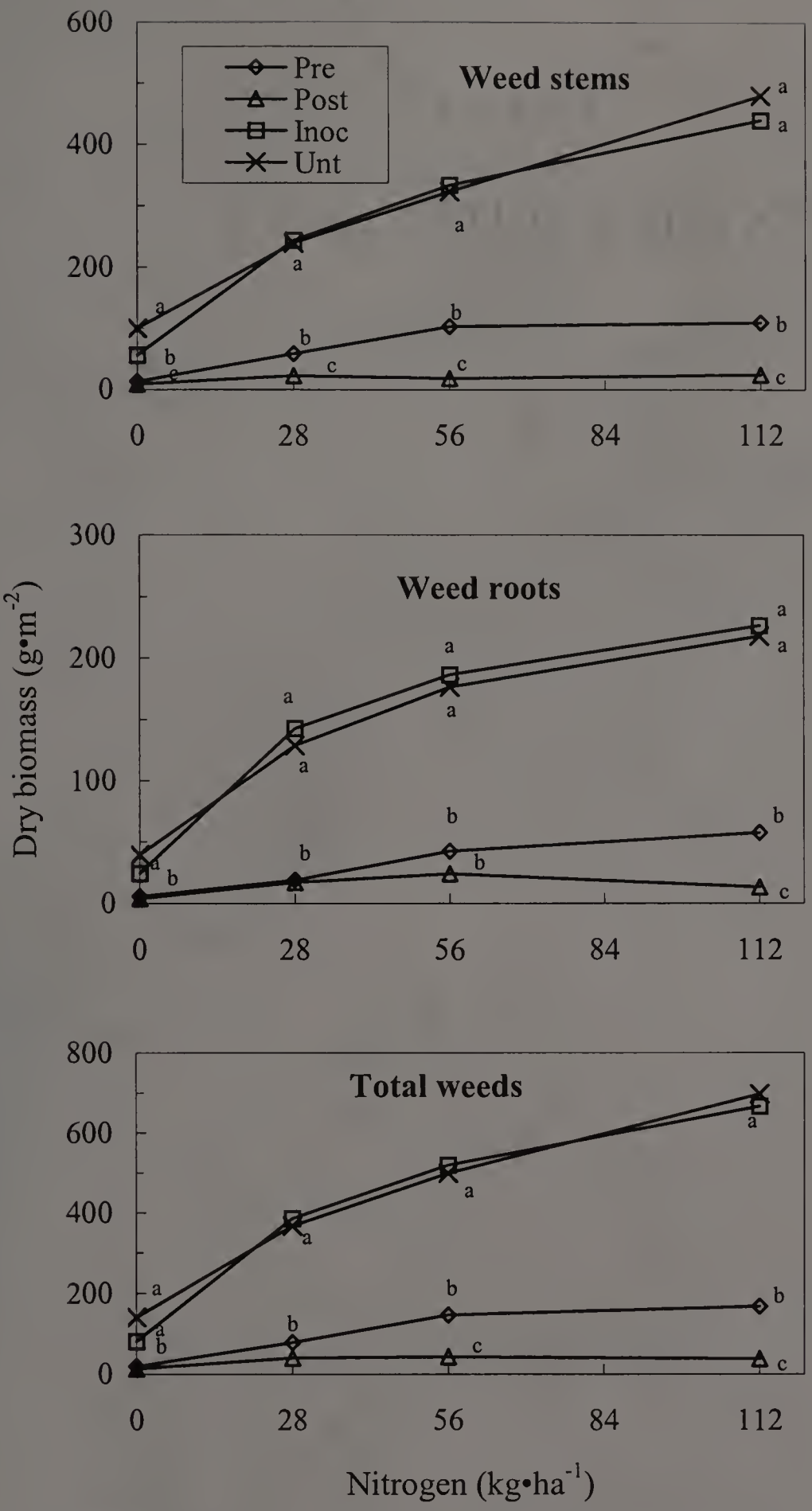


Figure 3.23. Interaction of nitrogen rate and weed management option on weed biomass during the first two years of vine growth (N=32). Significant differences among WMO occurred at all N rates for all parameters in both years. Within each N rate, means with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

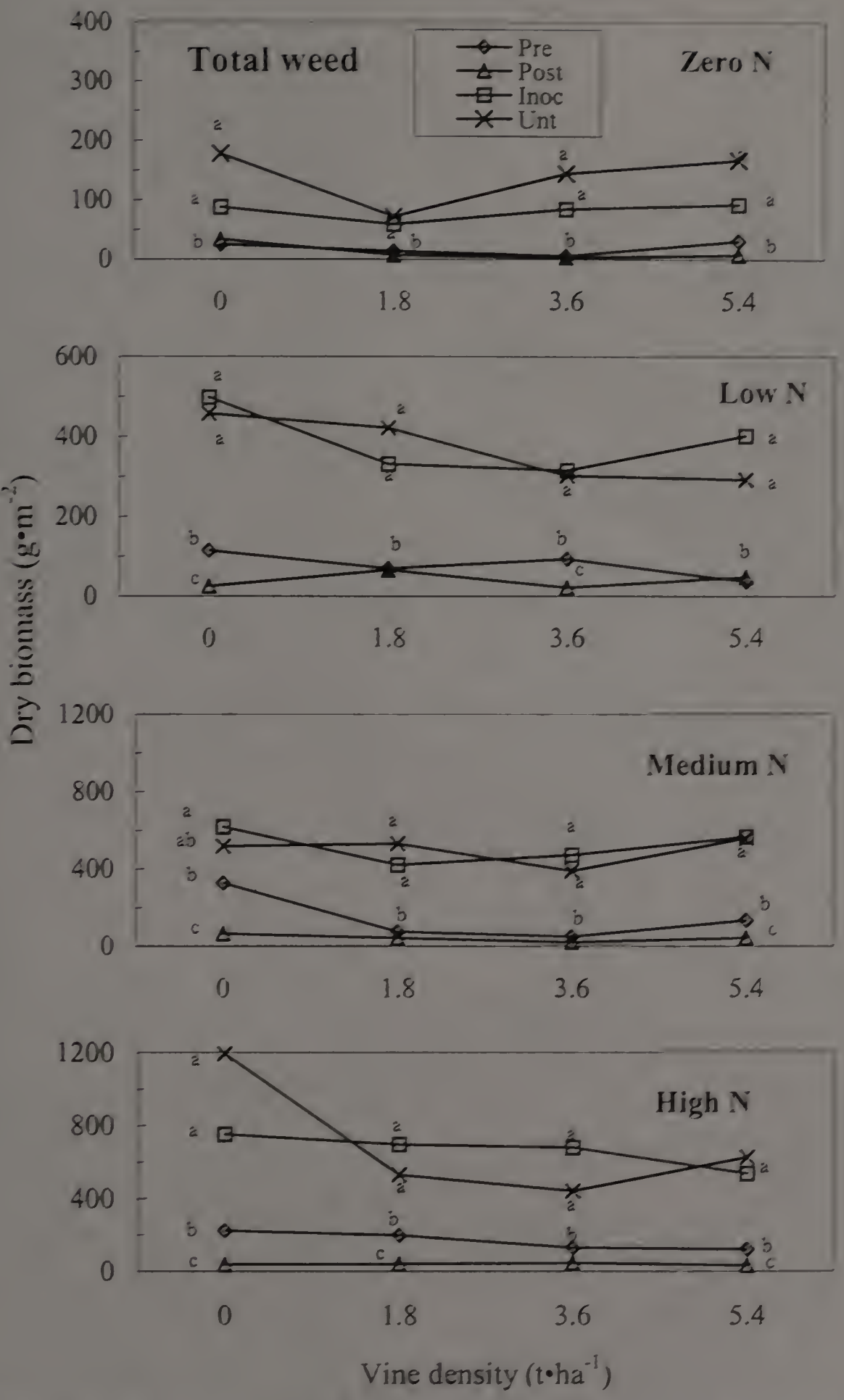
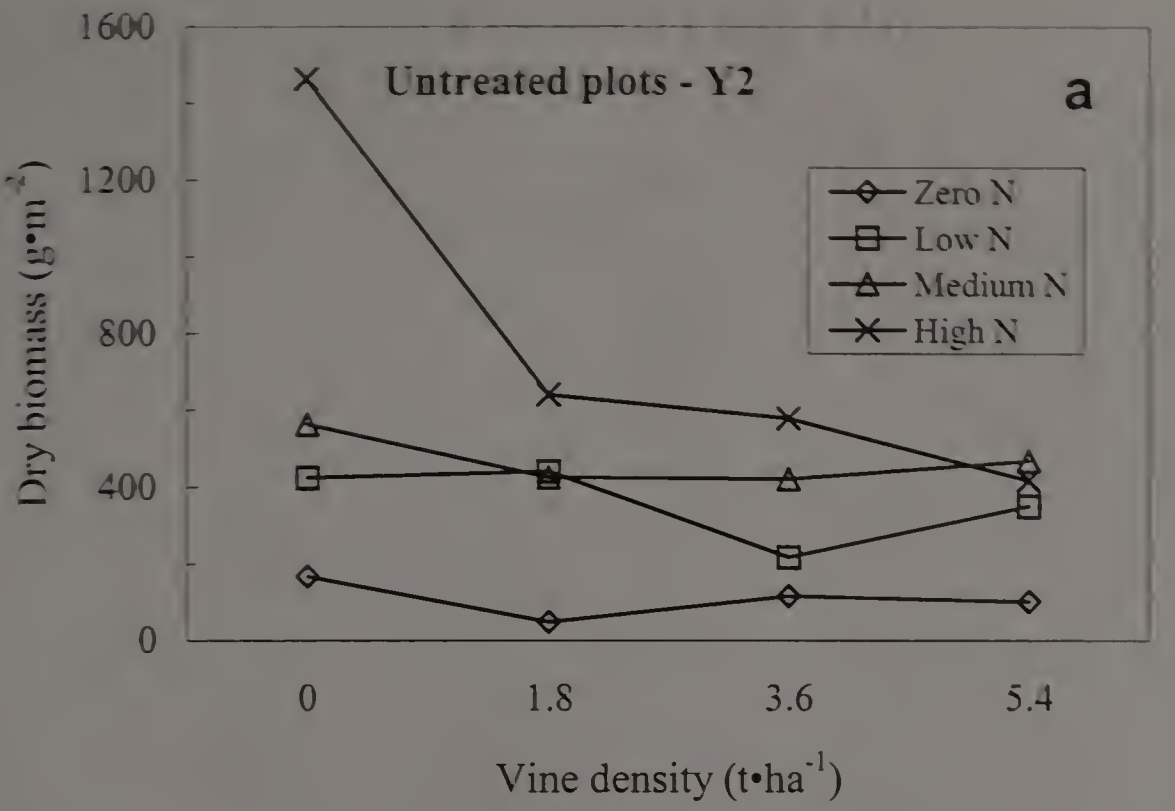


Figure 3.24. Interaction of nitrogen rate, vine density, and weed management option on total weed dry biomass during the first two years of vine growth (N=8). Significant differences among WMO occurred at all N rates. At each N rate, means with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).



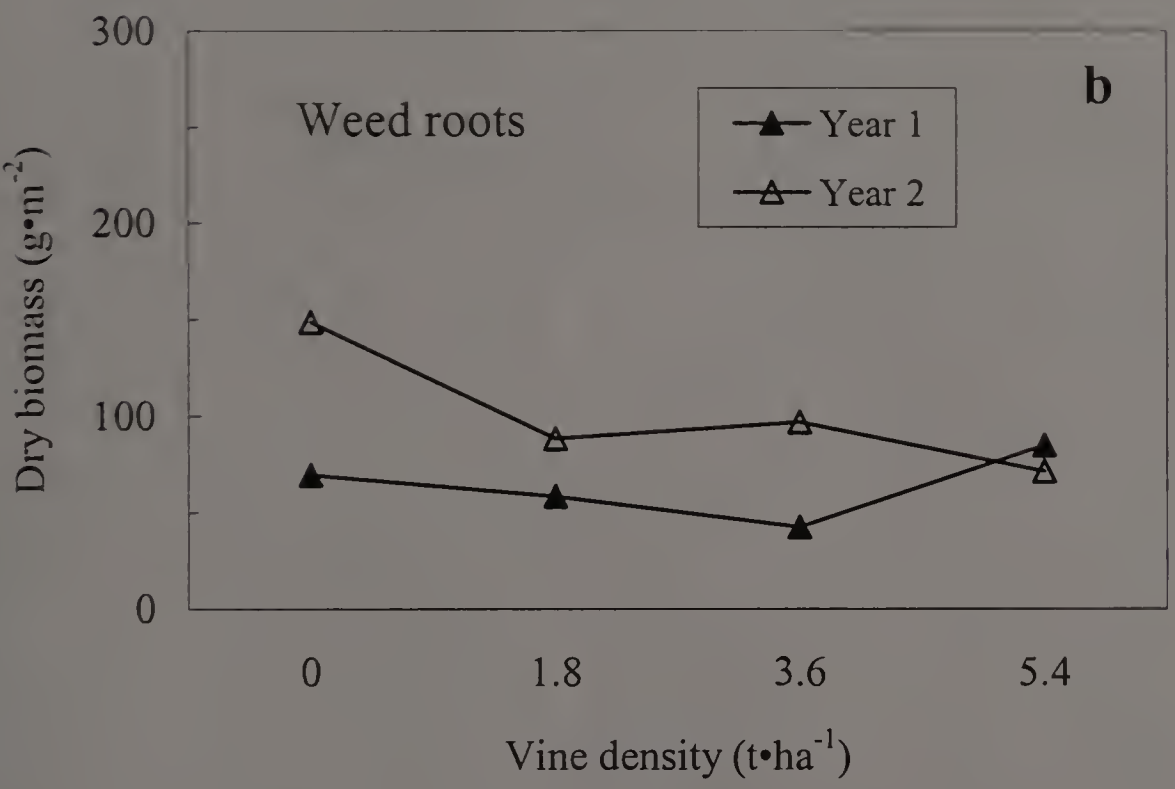


Figure 3.25. a) Interaction of vine density and nitrogen rate on total weed biomass produced in untreated plots in Year 2 (N=16), and b) effect of vine density on weed root biomass in Year 1 and Year 2 (N=64).

Table 3.12. Percentage cranberry biomass of total biomass collected from all weed management option plots (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cranberry					
			Stem[z]		Root[y]		Total[x]	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
0	0	Pre	1.5	0.0	0.0	0.3	1.3	0.0
		Post	0.0	2.6	0.0	0.4	0.0	1.9
		Inoc	0.0	0.0	0.0	0.0	0.0	0.0
		Unt	0.2	0.0	0.2	0.1	0.2	0.0
	1.8	Pre	88.7	93.9	97.3	85.7	90.0	92.2
		Post	95.4	97.7	98.5	88.1	96.1	95.3
		Inoc	60.0	85.7	64.7	65.7	60.9	83.2
		Unt	51.4	85.1	58.3	74.8	51.9	82.6
	3.6	Pre	98.4	96.0	99.3	92.8	98.7	95.7
		Post	98.7	98.8	98.0	98.1	98.5	98.7
		Inoc	62.2	88.0	70.4	61.8	63.7	81.9
		Unt	53.6	82.6	54.7	52.9	53.9	75.3
	5.4	Pre	91.6	95.2	85.2	85.8	89.3	93.9
		Post	95.0	98.7	94.8	91.1	95.0	98.2
		Inoc	69.6	80.1	69.8	37.7	69.7	71.4
		Unt	57.1	83.5	62.2	61.2	58.3	79.1
28	0	Pre	0.0	0.0	0.0	0.0	0.0	0.0
		Post	0.0	0.0	0.0	0.0	0.0	0.0
		Inoc	0.0	0.0	0.0	0.0	0.0	0.0
		Unt	0.0	0.0	0.0	0.0	0.0	0.0
	1.8	Pre	78.6	84.7	85.7	70.0	79.9	81.9
		Post	70.3	94.1	71.8	51.5	67.8	87.9
		Inoc	43.2	61.3	41.8	18.0	43.1	46.3
		Unt	24.2	54.9	21.9	18.1	23.6	40.9
	3.6	Pre	70.1	92.0	77.0	69.0	71.0	90.0
		Post	85.7	97.7	88.1	84.4	86.5	96.7
		Inoc	40.7	67.1	45.5	22.6	42.7	56.5
		Unt	38.7	70.5	44.1	49.1	40.6	66.0
	5.4	Pre	91.3	94.4	91.0	87.1	91.9	93.2
		Post	84.9	99.3	77.3	96.8	53.2	98.9
		Inoc	36.1	72.2	22.2	29.5	32.2	61.7
		Unt	52.7	69.4	50.5	40.4	81.3	62.4

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Table 3.12, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cranberry					
			Stem		Root		Total	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
56	0	Pre	0.0	3.6	0.0	0.3	0.0	1.9
		Post	2.0	1.5	0.0	0.0	1.6	0.7
		Inoc	0.1	0.0	0.1	0.0	0.1	0.0
		Unt	0.0	4.4	0.0	0.0	0.0	2.4
	1.8	Pre	69.9	93.0	76.1	86.4	71.4	91.7
		Post	94.3	94.7	89.9	74.2	93.7	89.7
		Inoc	27.7	59.0	28.7	18.7	27.3	49.8
		Unt	20.3	63.0	18.9	42.4	18.7	59.5
	3.6	Pre	85.3	95.6	75.9	87.0	84.9	94.2
		Post	97.6	98.2	91.6	80.9	96.8	94.8
		Inoc	40.7	57.8	32.3	20.2	38.1	48.2
		Unt	47.1	63.0	61.4	21.7	50.5	55.0
	5.4	Pre	62.6	90.9	72.9	71.6	64.3	87.3
		Post	89.8	98.5	84.0	73.7	88.6	93.8
		Inoc	27.6	62.4	12.0	27.3	23.4	55.2
		Unt	40.8	64.8	37.4	45.1	38.3	61.3
112	0	Pre	0.0	0.0	0.0	0.0	0.0	0.0
		Post	0.0	0.0	0.0	1.9	0.0	0.0
		Inoc	0.0	0.5	0.0	0.0	0.0	0.3
		Unt	0.1	0.1	0.0	0.0	0.1	0.0
	1.8	Pre	67.9	80.2	92.0	51.7	73.1	74.0
		Post	92.2	92.7	86.9	60.4	91.5	90.2
		Inoc	22.8	45.6	38.3	4.0	24.2	35.4
		Unt	38.8	52.2	48.6	17.5	41.5	46.7
	3.6	Pre	89.4	89.3	93.0	73.0	90.0	85.4
		Post	90.5	96.6	84.2	68.4	89.5	93.6
		Inoc	24.7	54.1	26.5	17.0	24.4	45.8
		Unt	45.5	65.6	44.9	32.0	45.8	57.2
	5.4	Pre	81.9	89.9	82.0	82.7	81.5	88.9
		Post	93.0	97.3	88.4	91.2	91.8	96.8
		Inoc	37.7	62.6	23.1	28.8	35.3	57.1
		Unt	30.1	69.1	22.3	37.9	27.5	62.7

First two years

[z]Percentage cranberry as above biomass was affected by N*D, N*WMO, and D*WMO ($P \leq 0.029$).

[y]Percentage cranberry as below biomass was affected by D*WMO ($P < 0.001$).

[x]Percentage cranberry of total biomass was affected by N*D, N*WMO, and D*WMO ($P \leq 0.024$).

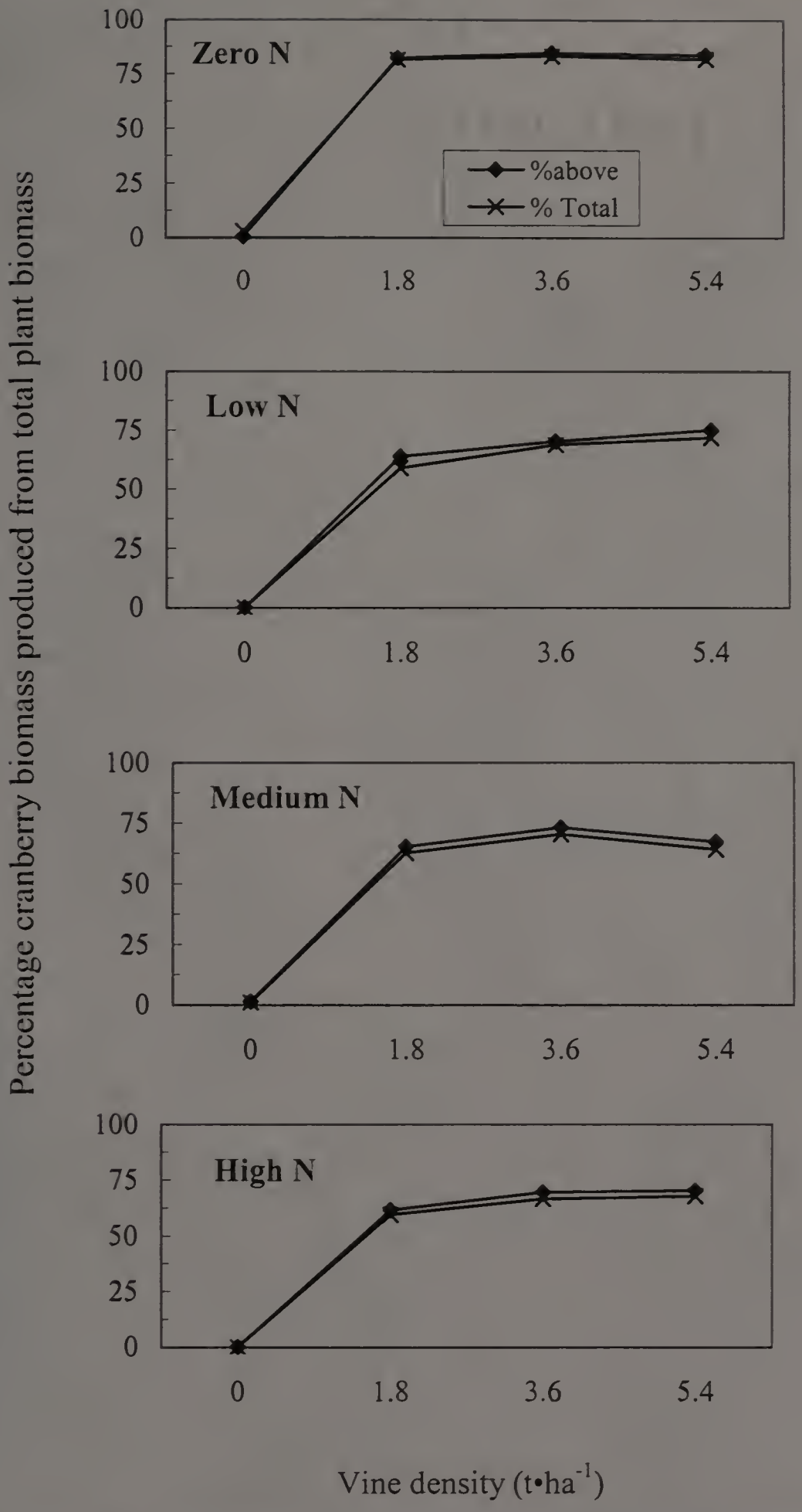

Figure 3.26. Interaction of nitrogen rate and vine density on cranberry biomass as percentage of aboveground and total biomass during the first two years (N=32). Significant differences among density occurred at all N rates for both parameters.

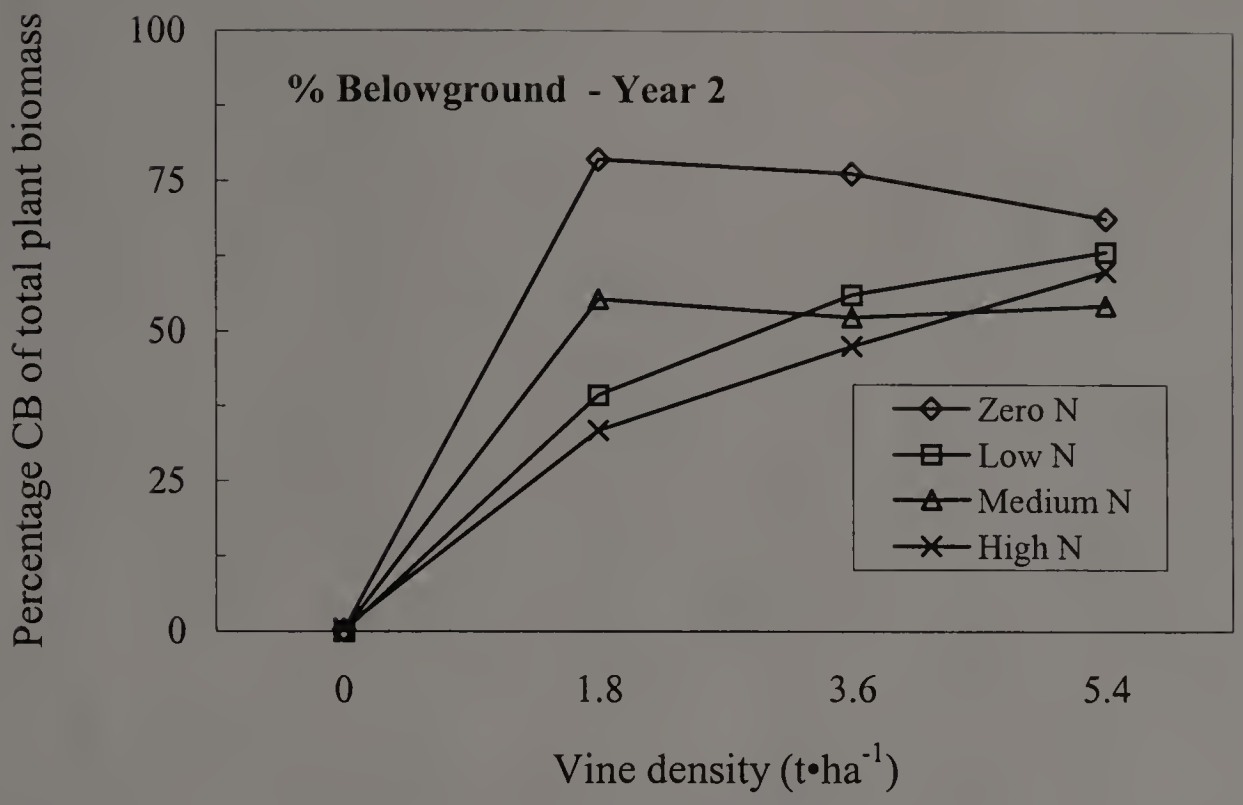

Figure 3.27. Interaction of vine density and nitrogen rate on cranberry biomass produced as percentage of belowground biomass during Year 2 (N=16). Significant differences among densities occurred at all N rates.

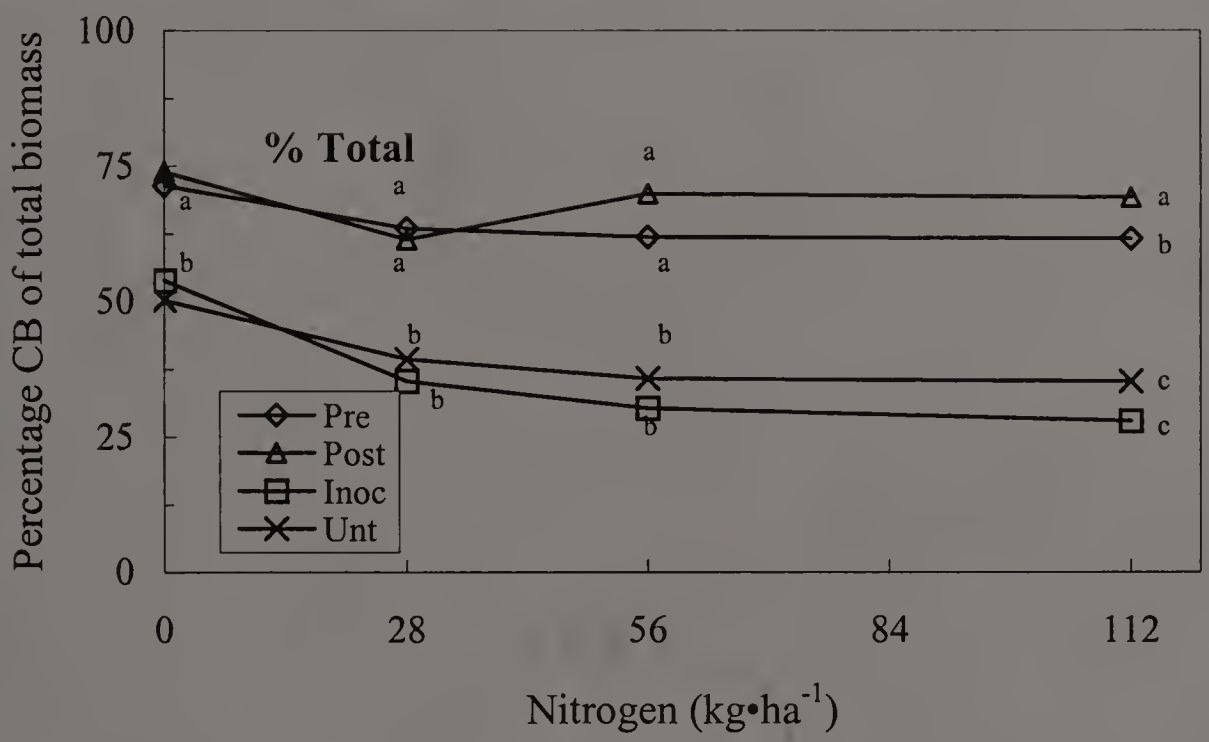

Figure 3.28. Interaction of nitrogen rate and WMO on cranberry biomass produced as percentage of total biomass produced during the first two years (N=32). Significant differences among WMO occurred at all N rates. Means, within each N level, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

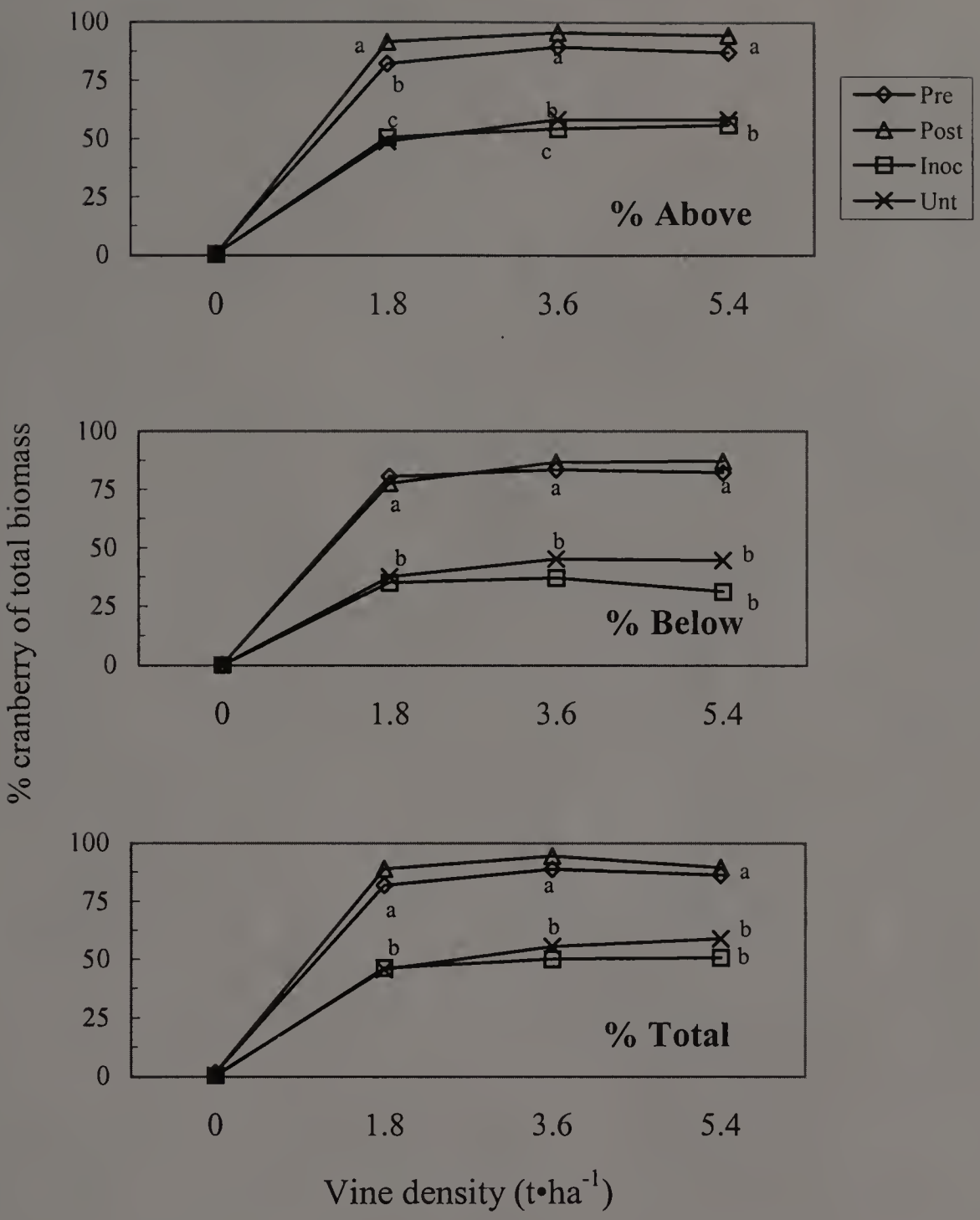

Figure 3.29. Interaction of vine density and weed management option on cranberry biomass produced as percentage of aboveground, belowground, and total biomass during the first two years (N=32). For all parameters, significant differences among WMO occurred at all densities except zero. Means, within each density, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

Table 3.13. Percentage light penetration from plots receiving various nitrogen, vine density, and weed management option treatments (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage light penetration[z]			
			July Y1	Aug. Y1	July Y2	Aug. Y2
0	0	Pre	95.8	97.3	98.0	91.3
		Post	93.8	97.3	96.5	98.8
		Inoc	98.3	89.8	96.5	89.3
		Unt	96.5	84.3	96.3	90.8
	1.8	Pre	95.8	96.8	94.5	91.5
		Post	91.8	96.5	91.3	90.5
		Inoc	95.5	81.5	97.5	88.3
		Unt	96.3	89.0	89.3	87.5
	3.6	Pre	94.8	94.8	83.5	80.0
		Post	90.8	97.3	89.8	84.5
		Inoc	86.0	82.0	87.8	77.3
		Unt	87.5	81.0	85.8	78.0
	5.4	Pre	88.0	95.0	87.5	80.3
		Post	90.0	95.3	82.3	74.3
		Inoc	93.3	88.0	86.8	78.5
		Unt	90.3	75.0	72.5	65.5
28	0	Pre	98.0	87.0	96.3	84.5
		Post	98.3	95.3	97.0	94.8
		Inoc	91.5	60.5	95.0	61.3
		Unt	90.3	69.5	89.5	58.8
	1.8	Pre	94.3	88.8	79.8	70.8
		Post	91.0	95.8	88.0	74.5
		Inoc	91.0	60.3	85.3	66.8
		Unt	85.3	65.0	78.3	42.3
	3.6	Pre	92.3	83.3	85.3	72.5
		Post	90.5	96.0	82.3	66.5
		Inoc	94.3	64.8	87.5	67.8
		Unt	88.5	70.5	71.0	50.5
	5.4	Pre	90.0	90.8	74.0	69.3
		Post	88.3	97.8	75.0	59.3
		Inoc	79.0	68.0	67.3	59.8
		Unt	85.8	64.8	70.8	44.5

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Table 3.13, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage light penetration			
			July Y1	Aug. Y1	July Y2	Aug. Y2
56	0	Pre	97.5	86.3	85.3	62.3
		Post	85.3	99.5	83.3	95.3
		Inoc	93.8	50.3	79.3	40.5
		Unt	92.3	69.3	83.5	38.5
	1.8	Pre	95.0	74.0	79.3	54.8
		Post	89.0	94.3	68.8	44.3
		Inoc	89.3	51.5	72.8	36.8
		Unt	65.3	40.3	48.8	14.8
	3.6	Pre	89.0	92.3	62.5	60.0
		Post	88.8	95.3	68.0	61.5
		Inoc	80.3	57.0	74.0	42.5
		Unt	87.3	63.8	57.3	20.0
	5.4	Pre	88.3	72.0	55.0	33.0
		Post	82.5	95.8	66.3	46.8
		Inoc	74.3	35.3	67.0	47.0
		Unt	71.3	33.0	55.5	23.3
112	0	Pre	96.8	79.5	74.0	50.8
		Post	97.5	96.5	72.5	94.3
		Inoc	88.8	44.3	73.0	35.5
		Unt	81.0	34.0	48.3	13.8
	1.8	Pre	97.0	74.3	72.5	38.5
		Post	92.8	96.5	66.0	49.0
		Inoc	91.0	48.3	58.3	18.5
		Unt	91.3	48.0	40.3	11.0
	3.6	Pre	92.5	74.8	51.0	38.0
		Post	88.8	90.0	45.3	34.3
		Inoc	78.0	29.0	33.0	11.3
		Unt	77.0	36.5	31.0	11.8
	5.4	Pre	92.3	86.0	52.5	30.3
		Post	89.5	93.3	50.5	33.0
		Inoc	76.8	34.8	46.0	15.5
		Unt	81.3	47.8	42.5	18.3

[z]N*W affected light penetration in July 00, Aug. 00, and Aug. 01 ($P<0.026$).

N*D affected light penetration in Aug. 00 and Aug. 01 ($P<0.030$).

D*W affected light penetration in Aug. 01 ($P<0.001$).

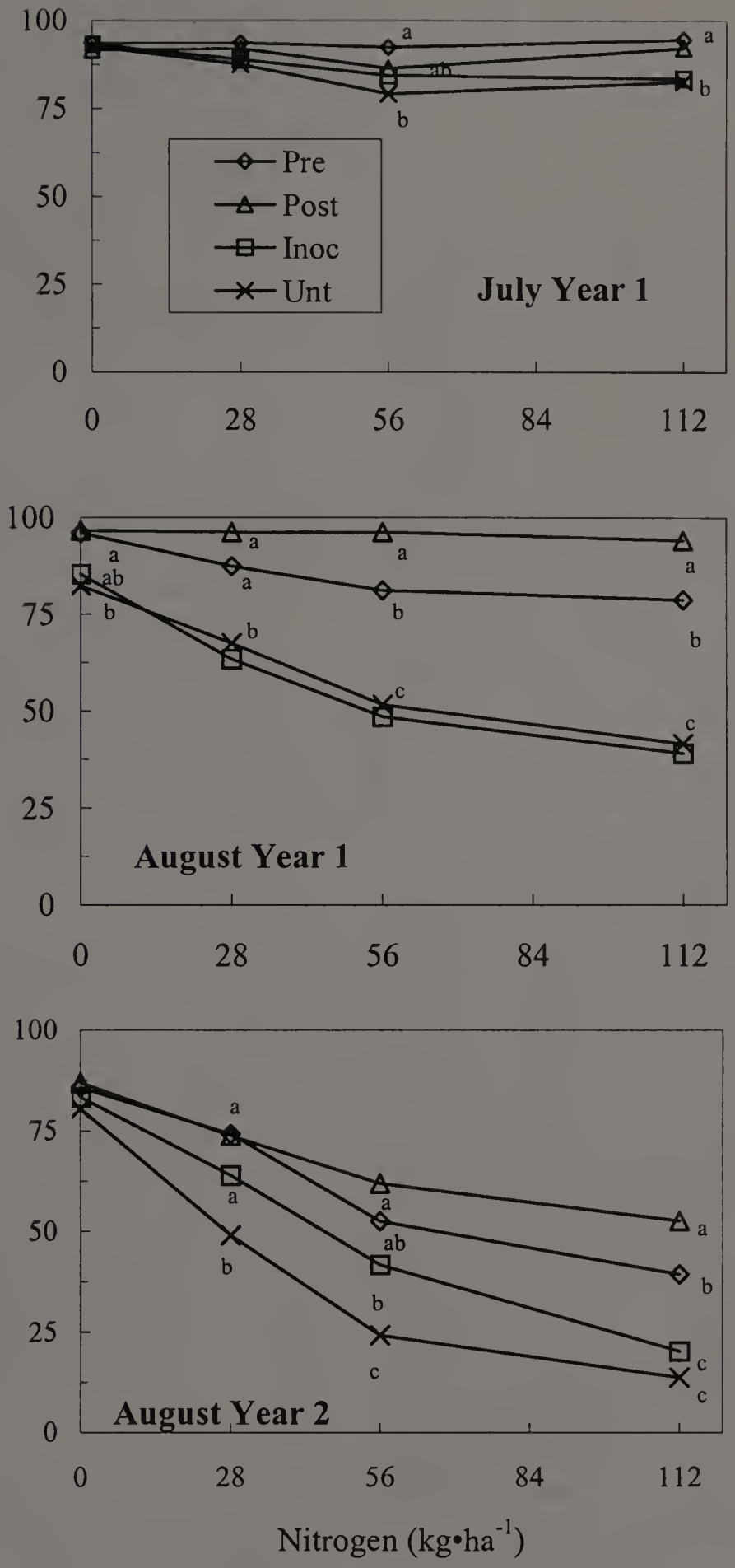

Figure 3.30. Interaction of nitrogen rate and weed management option on percentage light penetration in July and August-Y1 and August-Y2 (N=16). Significant differences among WMO occurred at medium and high N rates (July -Y1), all N rates (August-Y1), and low, medium, and high N rates (August-Y2). Means, within nitrogen levels, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

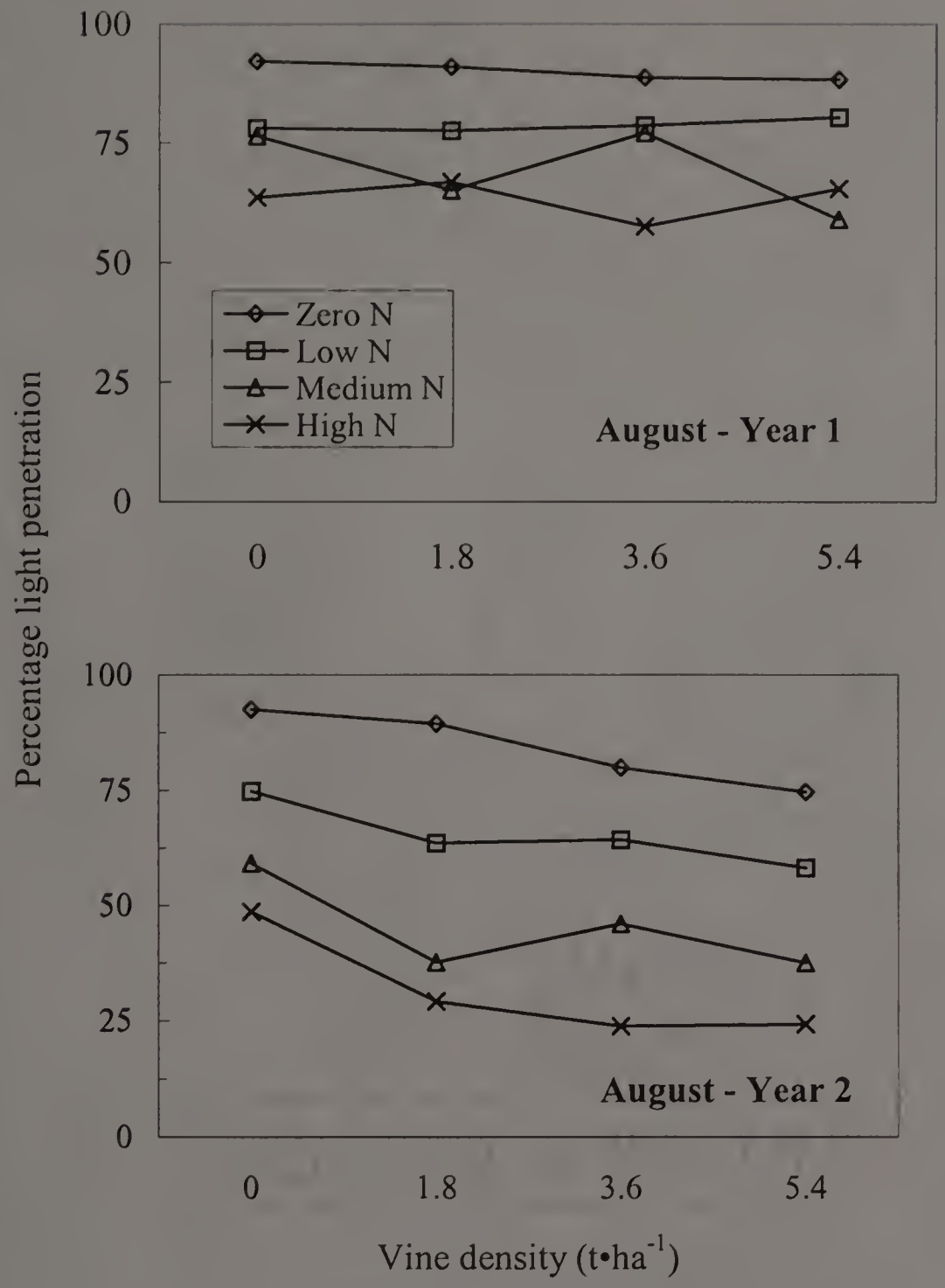

Figure 3.31. Interaction of nitrogen rate and vine density on percentage light penetration in August-Y1 and August-Y2 (N=16). Significant differences occurred among densities at medium N rates for August-Y1 and at all N rates for August-Y2.

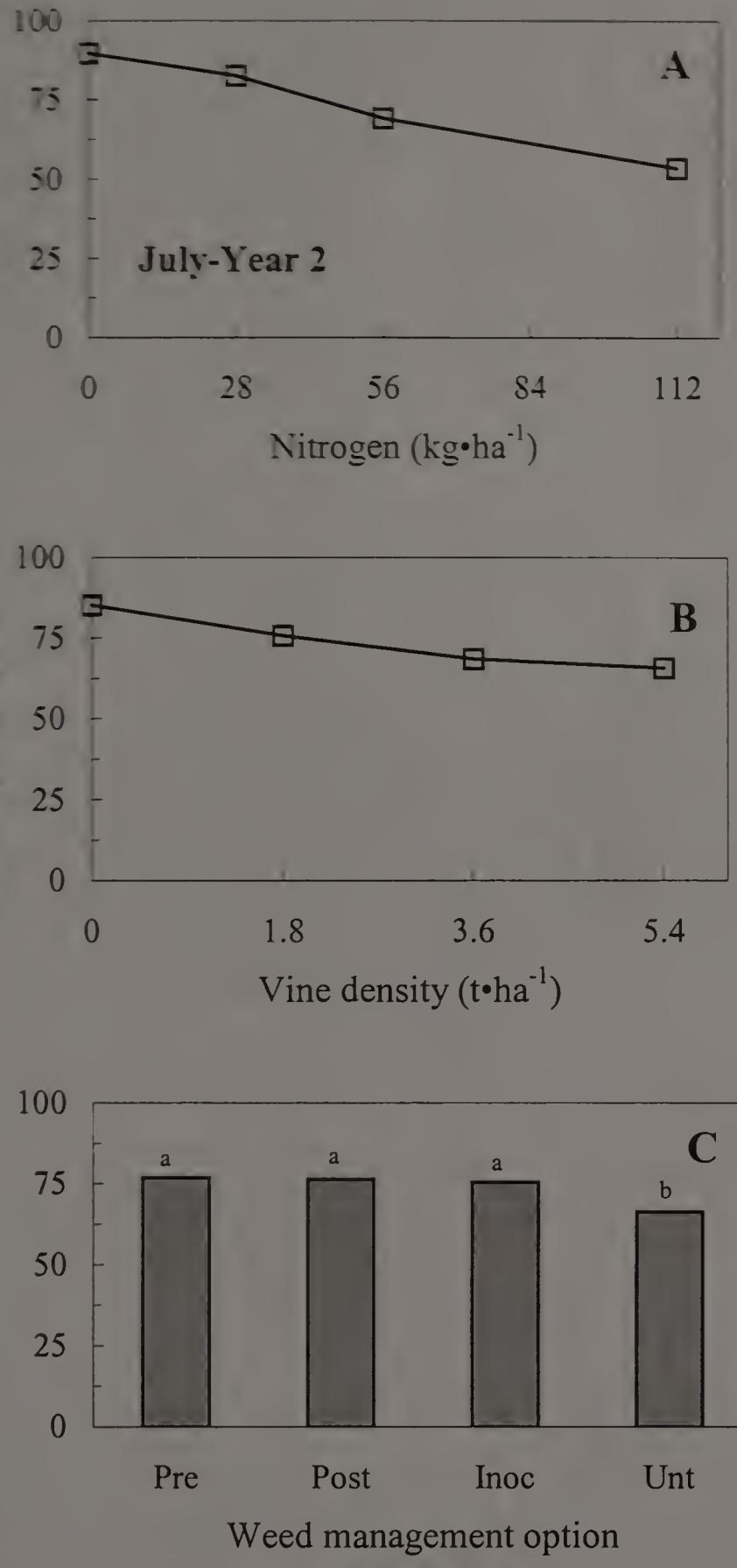

Figure 3.32. Effect of nitrogen rate, vine density, and weed management option on percentage light penetration in July-Y2 (N=64). Means with similar letters are not significantly different according to Kramer-adjusted Tukey's HSD (P=0.05).

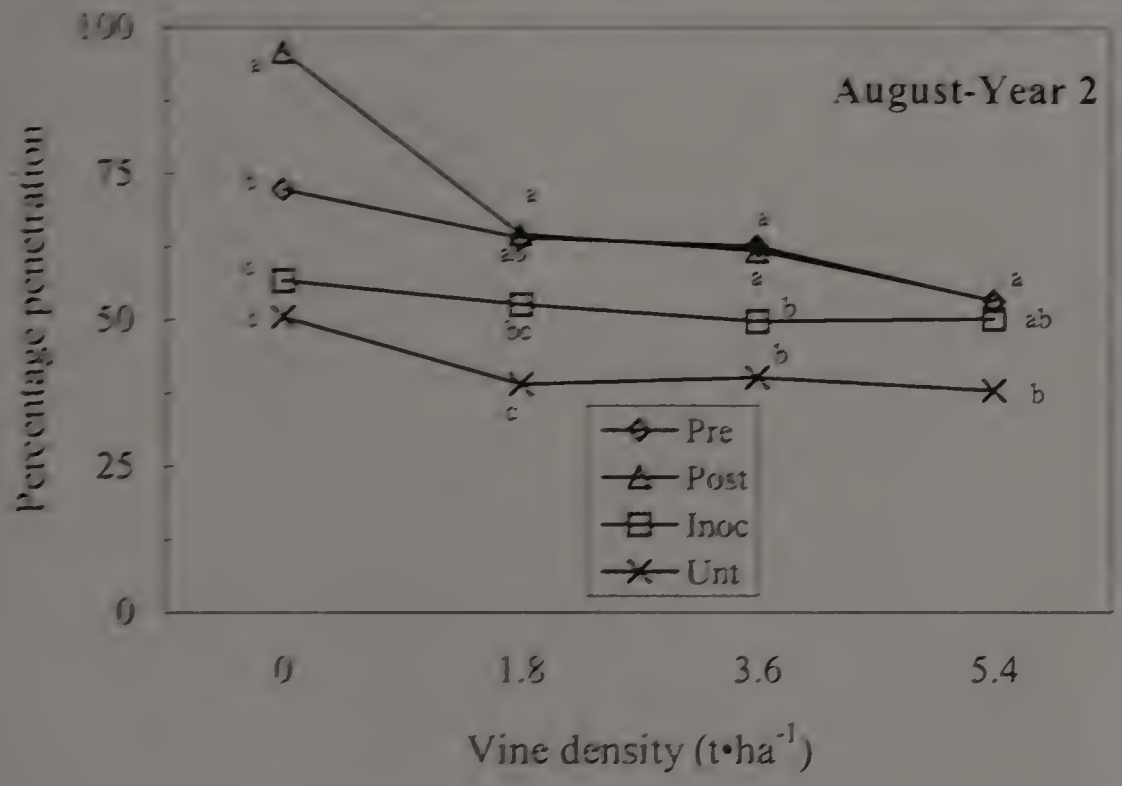

Figure 3.33. Interaction of vine density and weed management option on percentage light penetration in August-Y2 (N=16). Significant differences among WMO occurred at all density levels. Means, within density groups, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

Table 3.14. Major elements. Nutrient levels for cranberry vines collected from high-weed and low-weed areas in plots treated with various rates of nitrogen (N=4).

Year	Nitrogen ($kg \cdot ha^{-1}$)	Weed pressure	% Nutrients[z]				
			N	P	K	Ca	Mg
1	0	High	0.76	0.12	0.55	0.76	0.22
		Low	0.85	0.12	0.60	0.73	0.21
	28	High	0.89	0.12	0.64	0.55	0.18
		Low	0.94	0.13	0.70	0.46	0.18
	56	High	1.02	0.14	0.66	0.50	0.18
		Low	1.05	0.14	0.72	0.39	0.16
	112	High	1.23	0.15	0.79	0.35	0.14
		Low	1.24	0.16	0.91	0.26	0.14
2	0	High	0.85	0.15	0.46	1.00	0.24
		Low	0.88	0.15	0.49	1.00	0.24
	28	High	0.85	0.13	0.51	0.75	0.22
		Low	0.84	0.12	0.56	0.65	0.21
	56	High	0.91	0.13	0.54	0.55	0.20
		Low	0.94	0.14	0.63	0.40	0.19
	112	High	1.11	0.14	0.65	0.40	0.18
		Low	1.10	0.16	0.75	0.28	0.17

[z]In Y1 and Y2, fertilizer affected N, P, and Ca at $P \leq 0.001$ and $P \leq 0.001$, respectively.

During the first two years, fertilizer application and weeds interacted to affect K at $P=0.015$. Fertilizer affected Mg levels at $P<0.001$. Weeds affected Ca and Mg at $P<0.031$.

Table 3.15. Minor elements. Nutrient levels for cranberry vines collected from high-weed and low-weed areas in plots treated with various rates of nitrogen (N=4).

Year	Nitrogen ($kg \cdot ha^{-1}$)	Weed pressure	Nutrients (ppm)[a]					
			Zn	Cu	Mn	Fe	B	Al
1	0	High	23.5	12.5	863.0	158.3	42.3	130.8
		Low	24.0	12.8	803.5	146.0	39.0	134.3
	28	High	20.0	10.3	433.5	88.0	28.3	83.0
		Low	19.3	9.3	369.3	83.8	23.3	75.0
	56	High	23.3	12.3	531.0	98.3	30.0	90.3
		Low	22.0	13.8	359.3	93.8	23.5	79.8
	112	High	21.3	9.3	305.3	68.8	23.0	64.0
		Low	19.5	10.8	242.0	61.8	19.8	61.3
2	0	High	31.0	7.3	1019.5	112.3	47.0	121.3
		Low	30.3	7.0	758.8	113.0	45.8	132.5
	28	High	23.3	6.5	571.0	71.0	38.8	92.8
		Low	19.8	6.3	445.0	67.3	32.0	89.8
	56	High	19.0	6.3	357.3	59.0	27.5	79.5
		Low	17.0	6.3	220.5	46.0	23.5	66.3
	112	High	19.8	5.8	246.0	50.8	23.8	63.3
		Low	17.5	5.5	144.5	41.0	19.0	56.0

[a]In Y1 and Y2, fertilizer application affected Zn and B at $P \leq 0.048$ and $P < 0.001$, respectively.
During the first two years, fertilizer affected Mn, Al, and Fe levels at $P \leq 0.001$.
During the first two years, weeds affected Zn, Mn, and B levels at $P \leq 0.040$.

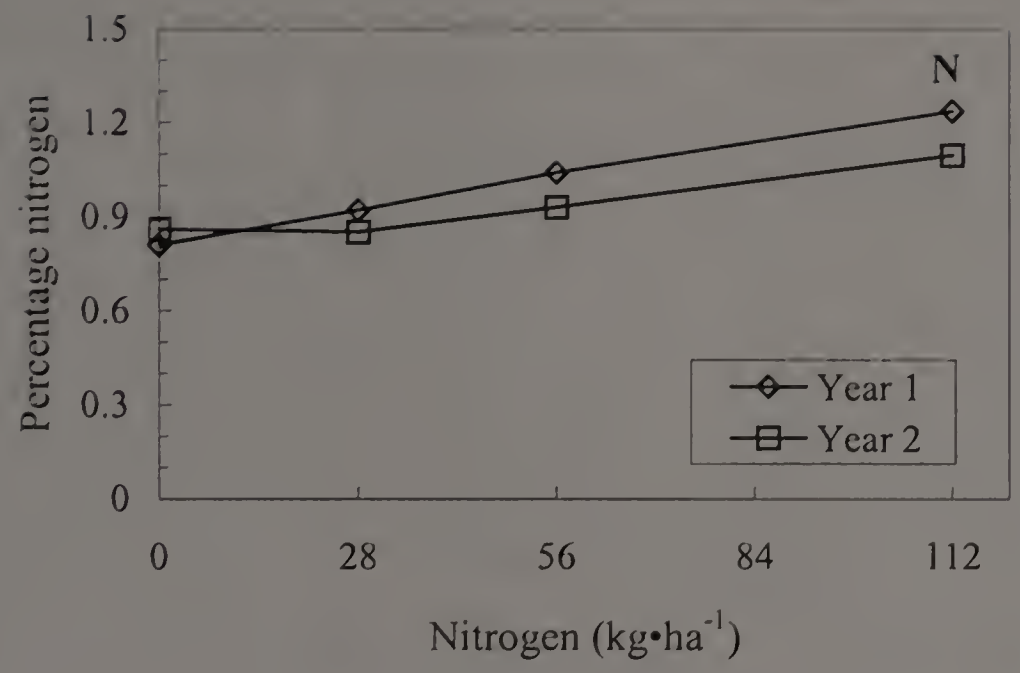

Figure 3.34. Effect of fertilizer application on nitrogen levels in cranberry tissue in Year 1 and Year 2 (N=8). Standard range is 0.9% to 1.1%.

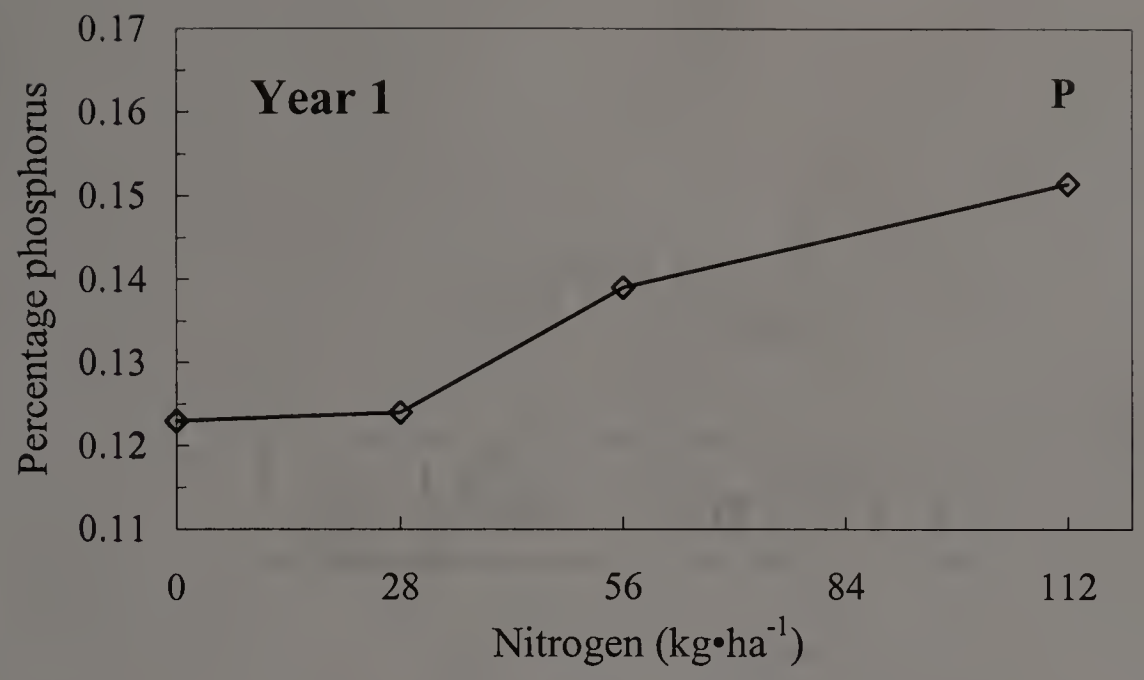

Figure 3.35. Effect of fertilizer application on phosphorus levels in cranberry tissue in Year 1 (N=8). Normal P values are between 0.1-0.2%.

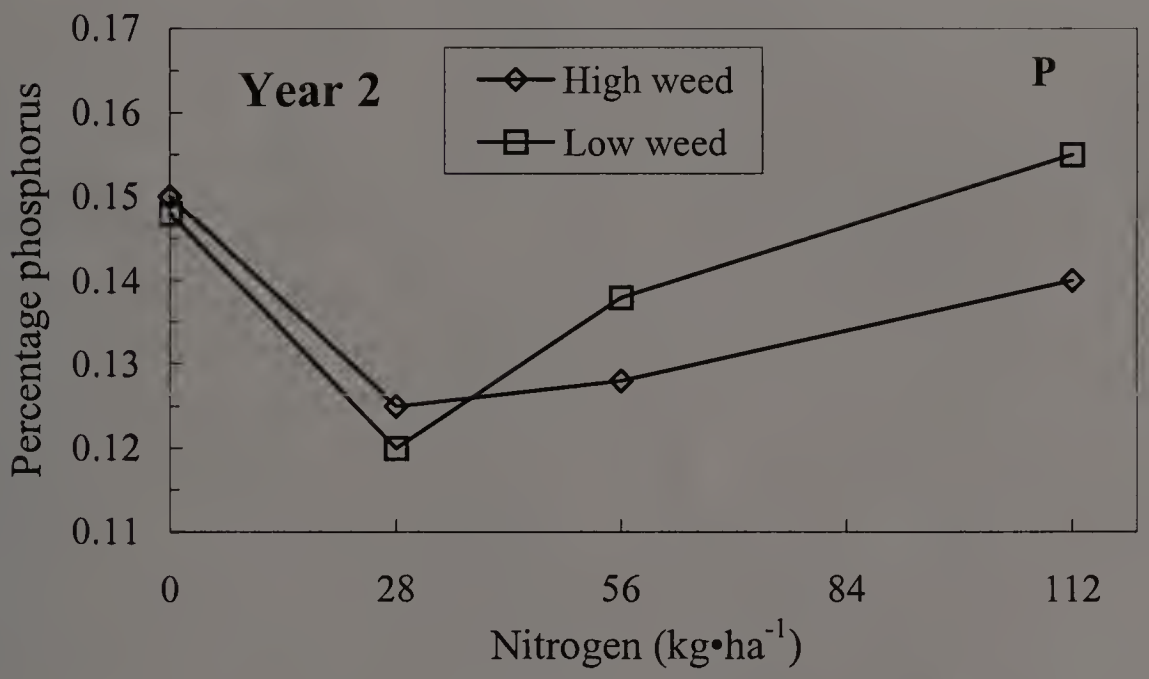

Figure 3.36. Interaction of fertilizer application and weed presence on phosphorus levels in cranberry tissue in Year 2 (N=4). Normal P values are between 0.1-0.2%.

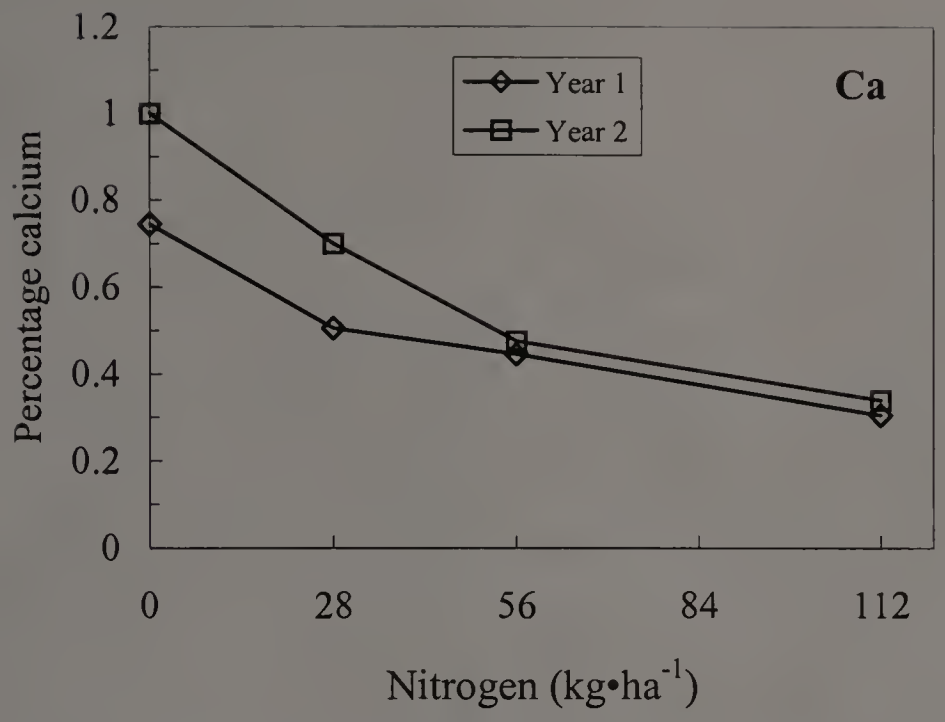

Figure 3.37. Effect of fertilizer application on calcium levels in cranberry tissue for Year 1 and Year 2 (N=8). Standard range is between 0.35% to 0.80%.

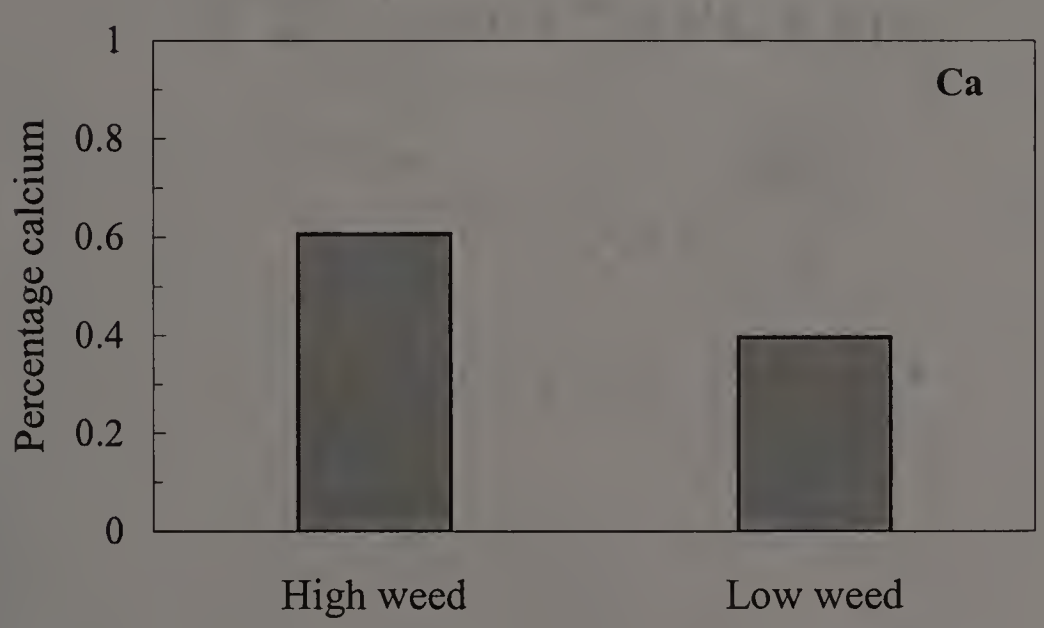

Figure 3.38. Effect of weed presence on calcium levels in cranberry tissue during during the first two years (N=32). Standard range is between 0.35% to 0.80%.

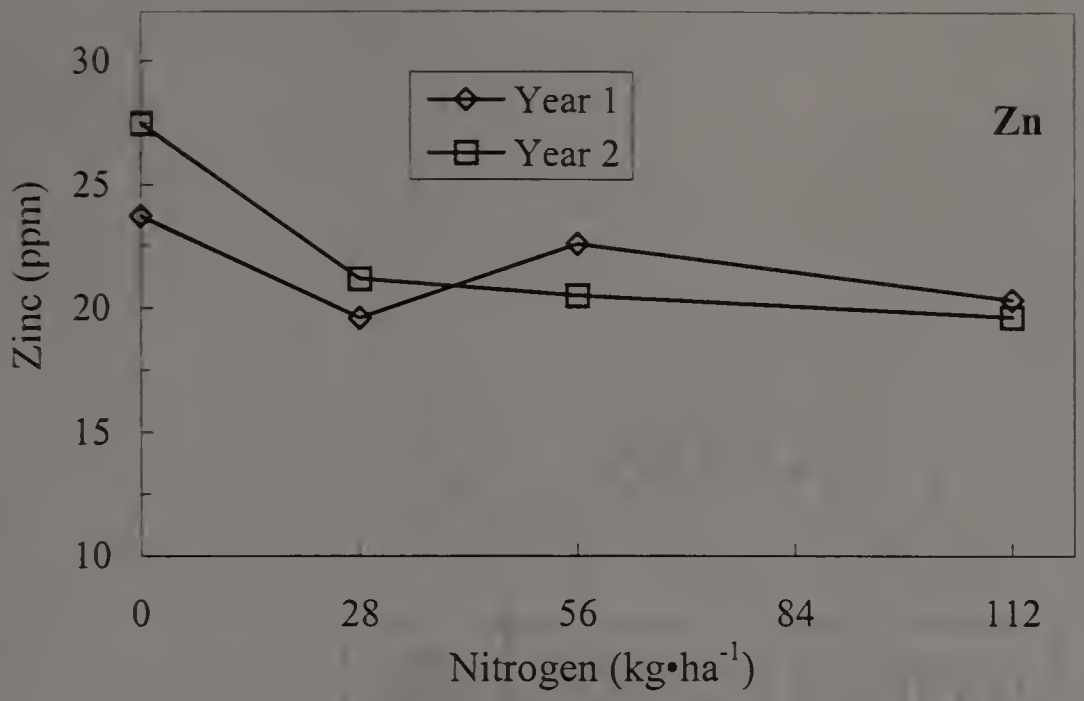

Figure 3.39. Effect of fertilizer application on zinc levels in cranberry tissue in Years 1 and 2 (N=8). Standard range is between 15 to 30 ppm.

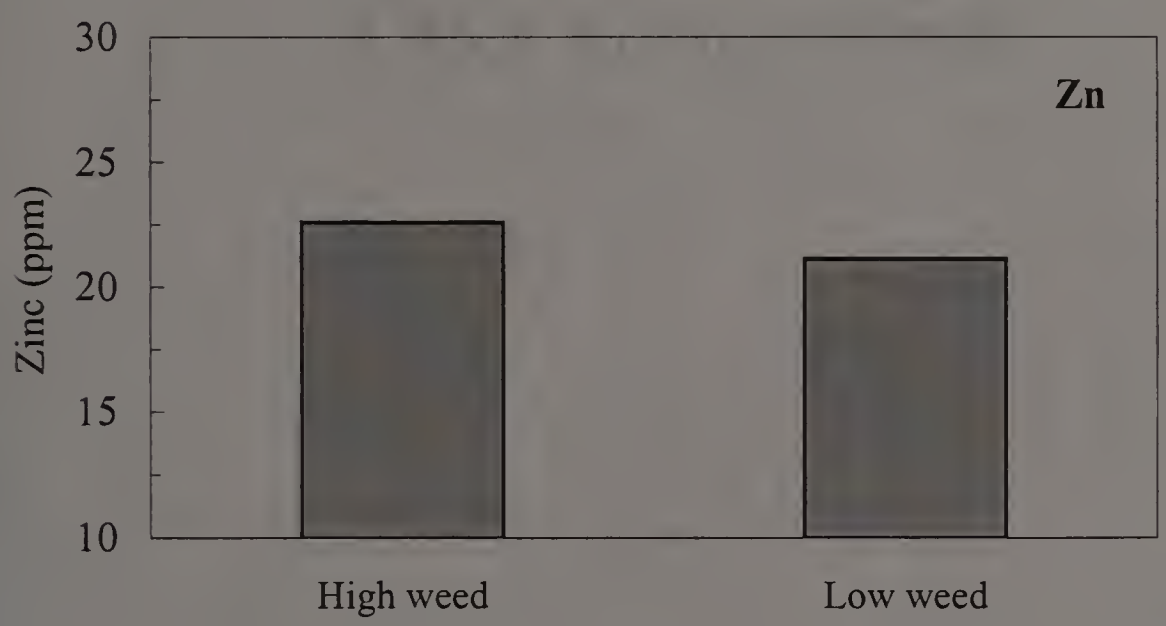

Figure 3.40. Effect of weed presence on zinc levels in cranberry tissue during the first two years (N=32). Standard range is between 15 to 30 ppm.

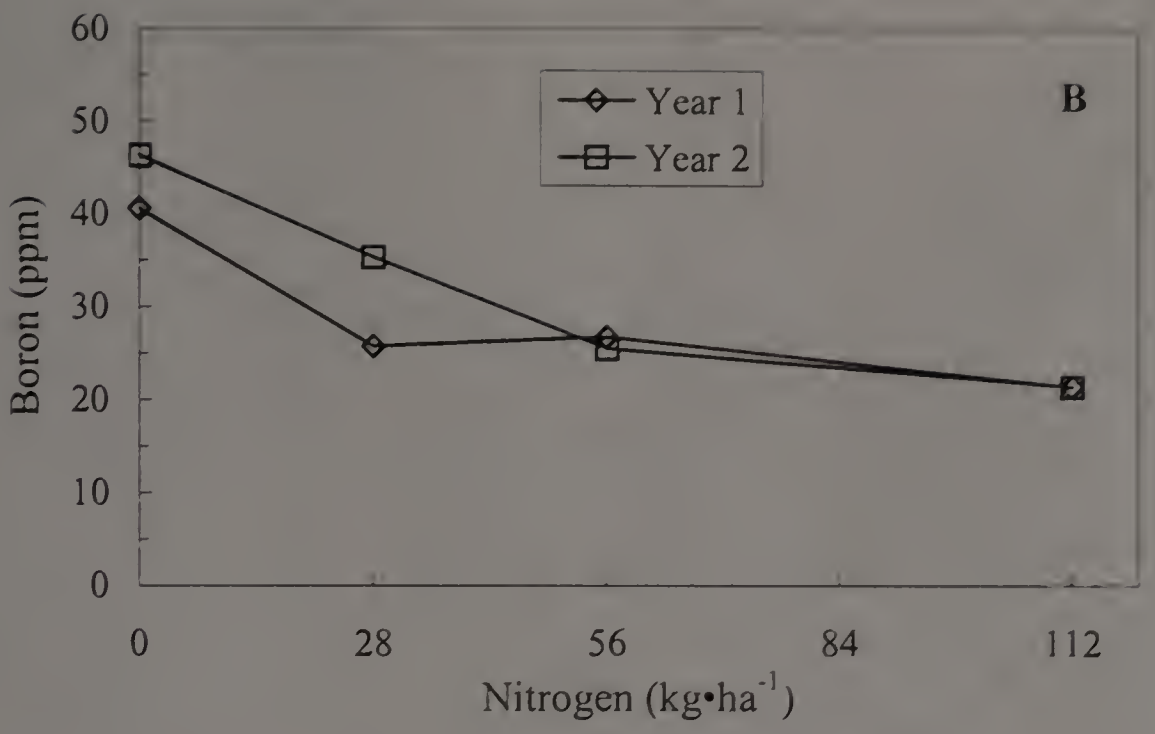

Figure 3.41. Effect of fertilizer application on boron levels in cranberry tissue for Years 1 and 2 (N=8). Standard range is 15 to 60 ppm.

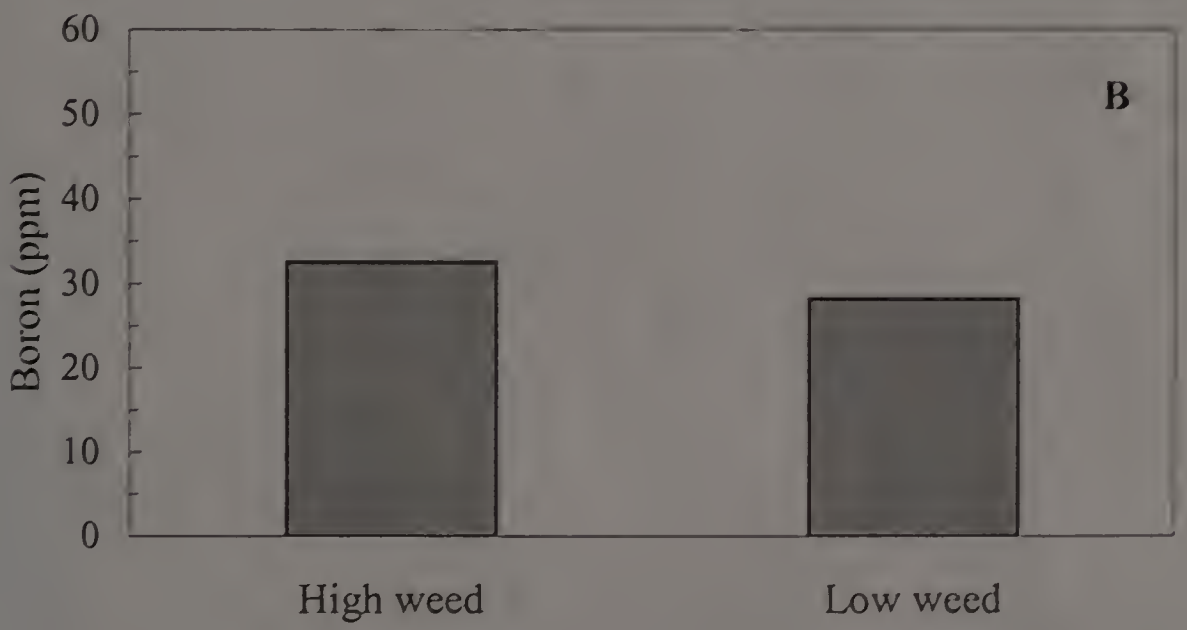

Figure 3.42. Effect of weed presence on boron levels in cranberry tissue during the first two years (N=32). Standard range is 15 to 60 ppm.

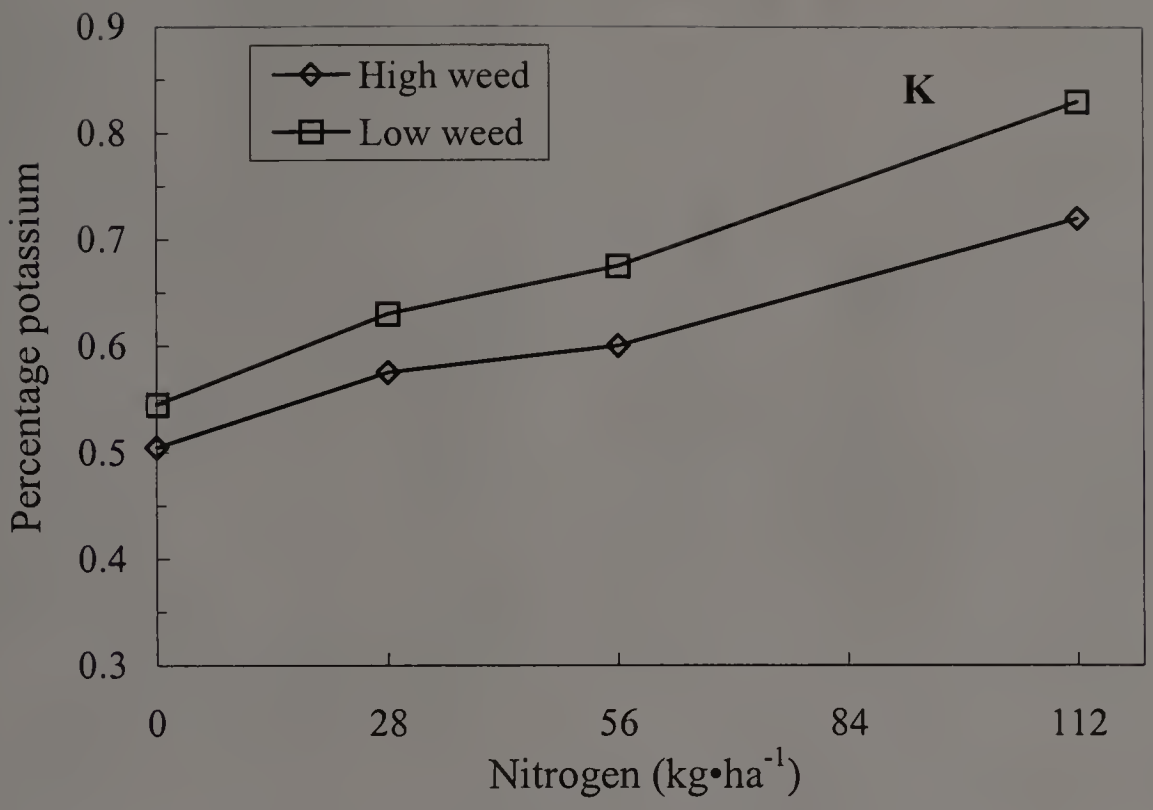

Figure 3.43. Interaction of fertilizer application and presence of weeds on potassium levels in cranberry tissue during the first two years of vine growth (N=8). Standard range is between 0.4% to 0.75%.

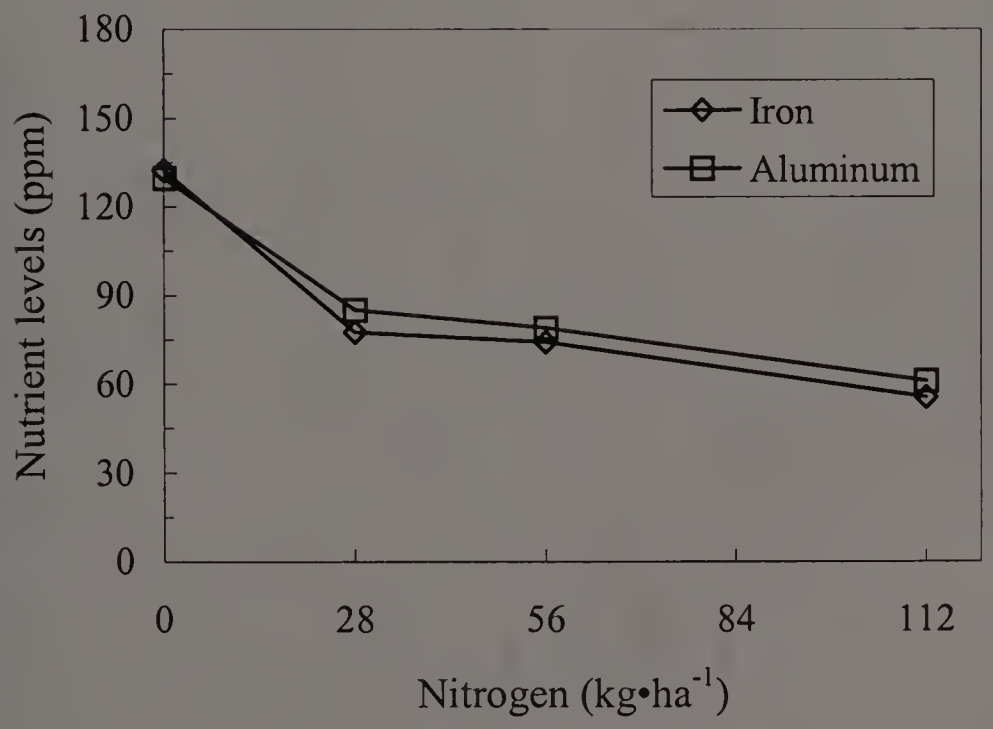

Figure 3.44. Effect of fertilizer application on iron and aluminum levels in cranberry tissue during the first two years of vine growth (N=16). Iron levels are only problematic if below 20 ppm; no standards available for aluminum.

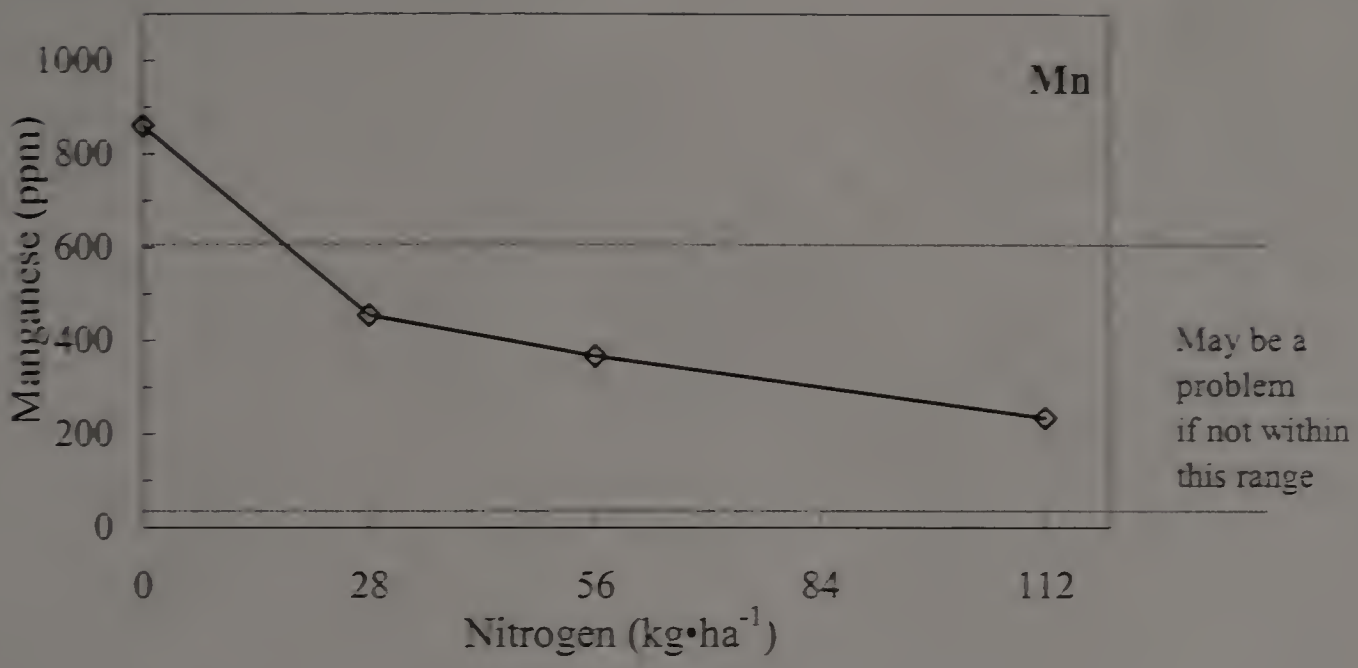

Figure 3.45. Effect of fertilizer application on manganese levels in cranberry tissue during the first two years (N=16).

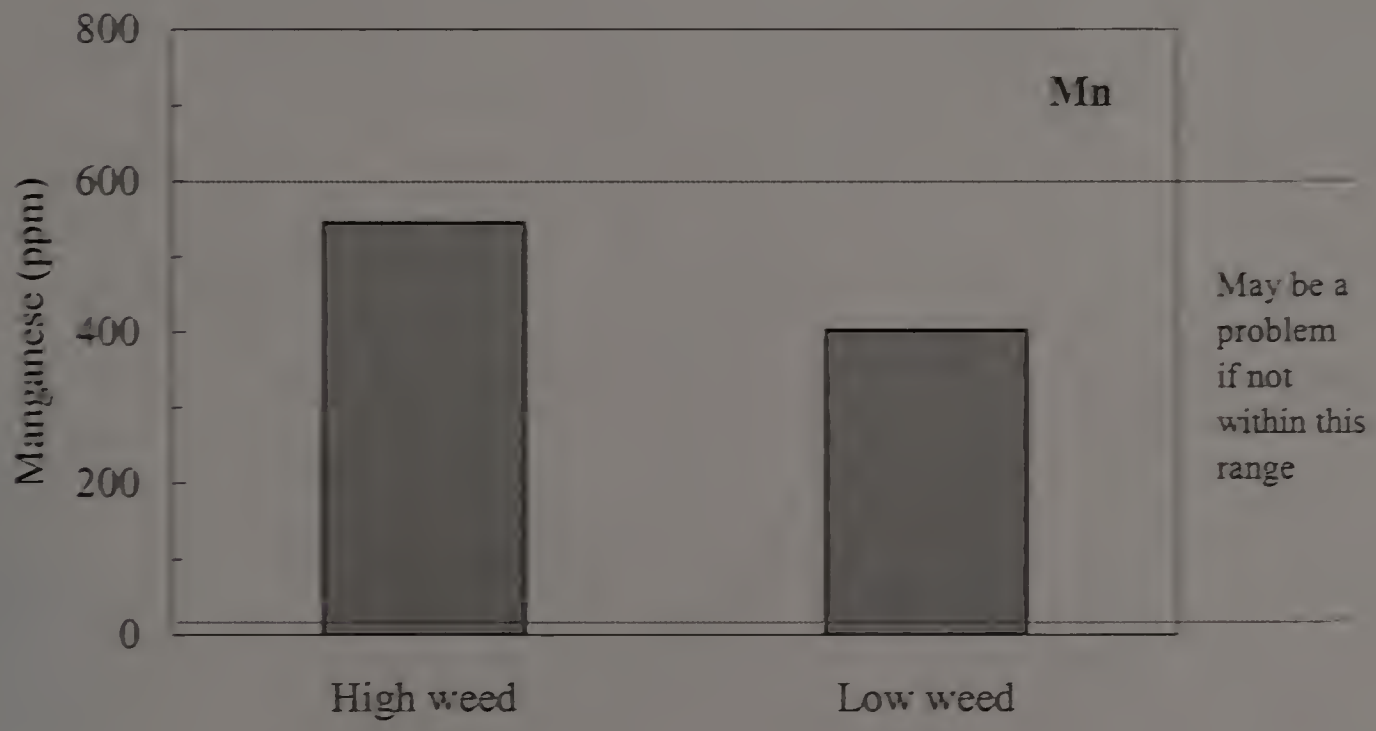

Figure 3.46. Effect of weed presence on manganese levels in cranberry tissue during the first two years (N=32).

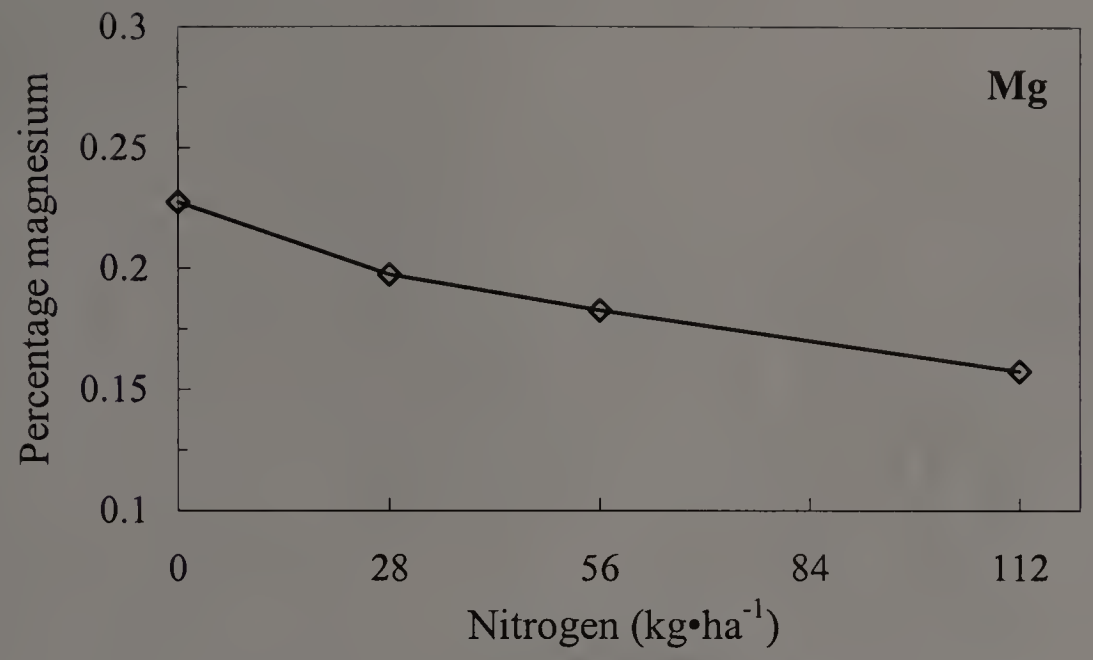

Figure 3.47. Effect of fertilizer application on magnesium levels in cranberry tissue during the first two years of vine growth (N=16). Standard range is between 0.15% to 0.25%.

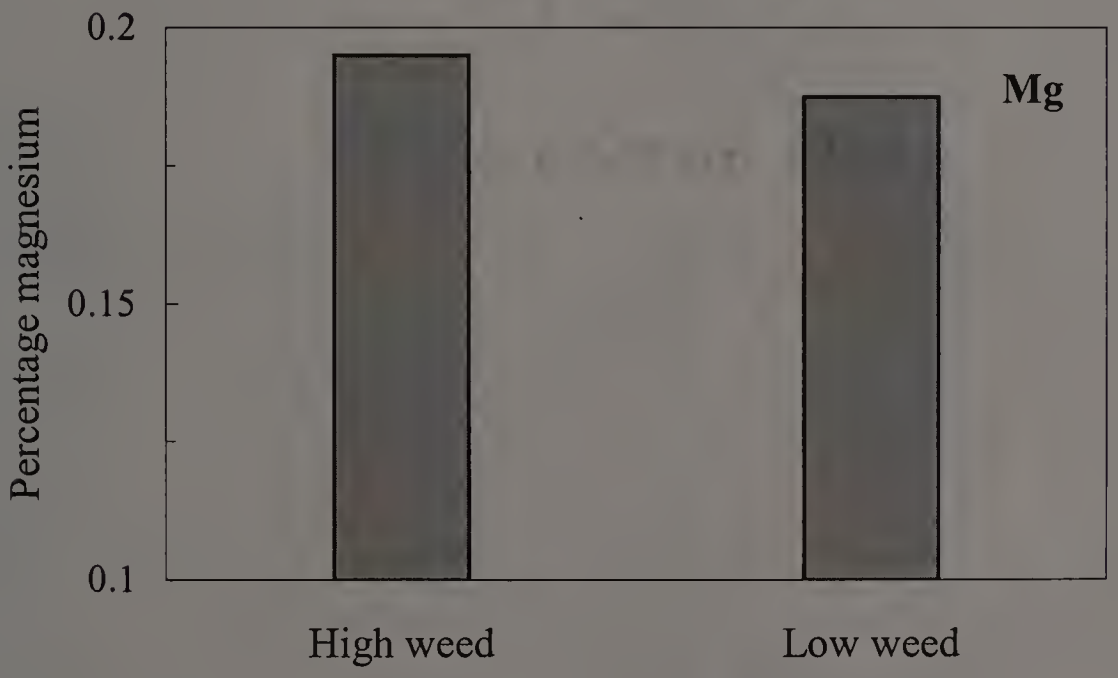

Figure 3.48. Effect of weed presence on magnesium in cranberry tissue during the first two years of vine growth (N=32). Normal range for Mg is 0.15-0.25%.

Table 3.16. Nitrate and ammonia-nitrogen levels determined from water samples collected at a 1-m depth from a central pipe located within each nitrogen treatment plot (N=4).

		Nitrogen concentrations (ppm)[z]					
	Nitrogen	Nitrate-N		Ammonia-N		Total-N	
Date	($kg \cdot ha^{-1}$)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1	0	0.25	0.00	5.15	1.15	5.40	1.15
	28	0.25	0.00	5.95	1.05	6.20	1.05
	56	0.38	0.00	5.53	1.15	5.90	1.15
	112	0.35	0.00	4.13	0.83	4.48	0.83
2	0	0.13	0.05	6.68	0.70	6.80	0.75
	28	0.10	0.00	4.68	0.58	4.78	0.58
	56	0.18	0.05	4.43	0.38	4.60	0.43
	112	0.13	0.13	4.70	0.60	4.83	0.73
3	0	0.58	0.00	5.05	0.80	5.63	0.80
	28	0.05	0.00	3.68	0.68	3.73	0.68
	56	0.13	0.15	4.75	1.00	4.88	1.15
	112	0.00	0.08	4.73	0.65	4.73	0.73
4	0	0.00	0.00	4.50	0.63	4.50	0.63
	28	0.00	0.00	4.05	0.20	4.05	0.20
	56	0.00	0.10	4.05	0.73	4.05	0.83
	112	0.00	0.00	4.05	0.98	4.05	0.98
5	0	0.00	0.00	4.20	0.45	4.20	0.45
	28	0.00	0.00	2.93	0.20	2.93	0.20
	56	0.00	0.00	3.55	0.70	3.55	0.70
	112	0.10	0.00	2.88	0.68	2.98	0.68
6	0	0.00	0.00	2.63	0.85	2.63	0.85
	28	0.00	0.00	1.43	0.78	1.43	0.78
	56	0.18	0.00	2.60	0.90	2.78	0.90
	112	0.00	0.00	2.68	1.03	2.68	1.03
7	0	0.00	0.00	2.60	0.13	2.60	0.13
	28	0.05	0.00	1.85	0.40	1.90	0.40
	56	0.00	0.00	1.50	0.58	1.50	0.58
	112	0.00	0.00	1.80	0.28	1.80	0.28

[z]ANOVA indicated $P>0.05$ for nitrogen treatment at all dates for both years.

Table 3.17. Top five three-way combinations for maximum cranberry biomass and minimal weed biomass, without vines becoming excessive.

Treatment combination	CB biomass ($g \cdot m^{-2}$)	Total (%)	Weed reduction (%)
Med-N/Med-D/Post	805	95	90
Med-N/High-D/Post	758	94	92
Med-N/Low-D/Pre	752	92	74
Low-N/Med-D/Pre	672	90	70
Med-N/Low-D/Post	661	90	80

CHAPTER 4

PLANT COMMUNITY COMPOSITION VARIES BY VINE DENSITY, NITROGEN RATE, AND WEED MANAGEMENT OPTION IN CRANBERRY

Introduction

Over 70 species of plants have been classified as weeds commonly found on commercial cranberry bogs (Demoranville, 1984; Demoranville, 1986; Sears et al., 1996). Approximately 48% of the species are broad-leaved plants, 25% are grass species, 14% are sedges, 7% are aquatic plants, 5% species are rushes, and 1% are parasitic plants. Many of these species have been identified as serious pests (Crop Profile, 2002) and can cause significant losses in cranberry production (Devlin and Deubert, 1980; Else et al., 1992; Mahr and Moffitt, 1994; Patten and Wang, 1994). Grower experience has certainly indicated that managing weed species in new plantings (either upland or renovated traditional production areas) is essential for minimizing costs and promoting quick coverage of the bog surface by vines.

In commercial cranberry plantings, weed losses may vary based on the species present, their ability to spread and cause yield loss, and available control techniques (Else et al., 1995). Common cranberry weeds have been given a priority ranking that enables growers to devise a weed management approach (Sandler, 2003). A successful weed management program must directly correspond to the specific composition of weed species that is present in any particular farm setting. Cultural practices, such as flood management and mowing, along with herbicide use, are important components of current integrated weed management techniques for established cranberry plantings. Understanding the interaction of available cultural practices, nutritional needs, and weed management is critical for promoting vine health, achieving good weed control and, ultimately, maximizing farm profits.

The interactions between the effects of tillage systems, crop rotation, and nitrogen on weed flora have been the subject of many studies in annual crops (O'Donovan et al., 1997; Anderson et al., 1998). As noted by others (Thomas and Frick, 1993; Anderson et al., 1998), results can vary widely, making generalizations about the response of weed associations in different cropping systems a difficult task. Utilizing data from a 9-year study, proper management with herbicides appeared to minimize any long-term effect on the weed flora from nitrogen rates in corn (*Zea mays* L.) (Swanton et al., 1999). Researchers also concluded that disturbance caused by tillage was more important than nitrogen rate in influencing the compositions of the weed flora. From another perspective, Anderson et al. (1998) reported that nitrogen fertilizer increased crop competitiveness in a spring-winter wheat (*Triticum aestivum* L.)-sunflower (*Helianthus annuus* L.) rotation with no-till, thereby reducing weed density. A Swedish study evaluating three 2-year rotations and four rates of nitrogen on weed flora indicated the greatest difference was between sites, and the second most important factor was crop species (Andersson and Milberg, 1998). An Italian research group reported that reduced tillage systems in corn and soybean (*Glycine max* (L.) Merrill) resembled the characteristics of a pioneer community, having a predominance of annual species and many wind-dispersed species (Zanin et al., 1997).

More recently, research efforts have focused on identifying ecological trends in weed community dynamics as affected by integrated crop management (ICM) practices (O'Donovan et al., 1997; Swanton et al., 1999). Diversity measurements, such as species richness and Shannon diversity index, have been used to evaluate the impact of herbicides on plant community composition. In a 5-year study, application of postemergence herbicides maintained weed diversity, reduced weed density, and inhibited community changes for various tillage systems involving the rotation of red spring wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), and flax (*Linum usitatissimum* L.) (Derksen et al., 1995). A recent study investigated plant community diversity associated with management of an invasive plant with herbicide

applications (picloram, clopyralid, and clopyralid + 2,4-D) over an 8-year period (Rice et al., 1997). Results showed that although herbicide applications controlled the target invasive weed, spotted knotweed (*Centaurea maculosa* Lam.), the weed management approach had minimal impact on diversity (species richness and Shannon diversity index) compared to untreated levels.

Unfortunately, research evaluating the interaction of cultural practices with other weed management strategies in perennial crop systems is sparse. The effects of cultivation (disturbance), herbicide application, and mulching on soil arthropods were evaluated over a 7-year period in asparagus (*Asparagus officinalis* L.) (Wardle et al., 1998). Arthropod species were positively correlated with high weed biomass (increased refugia and resource availability), and negatively correlated with crop biomass. Documentation of weed shifts associated with herbicide use alone in perennial fruit crops has been published in the literature. During the first 5 years of an apple (*Malus* sp., 'Starkrimson Delicious') orchard, dewberries (*Rubus* sp.) and Virginia clematis (*Clematis virginiana* L.) increased with terbacil usage, and *Rubus* sp. and goldenrod (*Solidago* sp.) increased with high and low rates of dichlobenil, respectively (Skroch, 1970). A long-term study (>15 yr) investigated the impact on coverage and weed abundance with use of a single herbicide (terbacil, diuron, or simazine) compared to the application of two herbicides together (all combinations) (Tworkoski et al., 2000). Results from this study agreed with previous work (Foy et al., 1994) showing that herbicides controlled the annual species but released perennial weed species.

Anecdotal evidence has indicated that certain weeds, such as nutsedge (*Cyperus dentatus* Torr.) and some grasses, such as *Panicum* sp., are problematic on newly planted cranberry farms. It has also been noted that other species, such as swamp dodder (*Cuscuta gronovii* Willd.), dewberries (*Rubus* sp.), and poison ivy (*Toxicodendron radicans* L.) do not become problematic until several to many years after planting. However, change in weed species composition over time in newly planted cranberry beds has not been documented. The impact of crop management choices, such as planting density and nitrogen rate, on the ability of cranberry to cover the bare

surface has not been quantified. In addition, the interaction of these choices, in conjunction with an initial weed management plan that can result in acceptable weed control, has not been evaluated.

The objectives of this study were to evaluate the interactions of nitrogen application, initial cranberry vine density, and weed management approach on the developing plant community, both cranberry and weeds. The following questions were addressed: What were the abundances of weed species during vine establishment? Did weed community composition change in the first two years of establishment? How did nitrogen rate, vine density, and weed management interact to affect the relative abundance of the weed species? Which treatment combination(s) favored cranberry vine establishment?

Materials and Methods

Experimental Design

A field trial was established in a renovated section (approximately 0.2 ha) at the State Bog at the UMass Cranberry Station, East Wareham, MA, in a fashion adapted from work presented by previous researchers (Burke and Grime, 1996). The following treatments were included in all combinations: 1) four nitrogen levels: 0, 28, 56, and 112 $kg \cdot ha^{-1}$; 2) four vine densities: 0, 1.8, 3.6, and 5.4 metric tons (t) per hectare of the cultivar, Stevens; and 3) four weed management options (WMO): natural recruitment (no weed control), inoculation with weed seeds, application of a preemergence herbicide, and postemergence control. The experiment was replicated four times in a randomized-complete-block-split-split-plot design (see Chapter 3). Each nitrogen plot (4 m x 8 m) was subdivided into four density subplots (2m x 4m each) and each density plot was subdivided into four WMO plots (1m x 2m each). An untreated lane of approximately 0.3 m separated each WMO from its nearest neighbor. Commercial vines were

pre-weighed for each density level, spread by hand, and disked in by a commercial planting machine on 4 May 2000. Vines were watered and fertilized as recommended for new cranberry plantings (DeMoranville et al., 2001).

Two comments, though mentioned previously in Chapter 3, are brought to the reader's attention for discussion related to this chapter. Though not technically a measure of plant density (i.e., no. plants/unit area), the term "vine density" is commonly used in commercial cranberry production to denote the amount of vine cuttings applied to an acre (DeMoranville et al., 2001; Strik, 2002) and is used throughout the manuscript. The preemergence and postemergence treatments are two possible weed management options that cranberry growers could use in a commercial setting; inoculation with weed seeds is not typically considered a "weed management option". However, the deposition of sand or vines that contain weed seeds is a potential problem that growers might encounter in newly planted beds (Sandler et al., 2001). For the purposes of this study, these weed treatments were collectively designated as weed management options (WMO).

In both 2000 and 2001, nitrogen was applied in five equal doses of 5.6, 11.2, and 22.4 $kg \cdot ha^{-1}$, alternately as urea (46N-0P-0K) or as a complete granular fertilizer proportioned as 19N-8.2P-15.8K. With the latter fertilizer, nitrogen was applied in the ammoniated form as cranberries preferably take up nitrogen in this form (Addoms and Mounce, 1932; Greidanus et al., 1972; Rosen et al., 1990). The plots designated to receive zero N did not receive any fertilizer inputs.

The preemergence WMO was an application of napropamide (N,N-diethyl-2-(1-naphthalenyloxy)propanamide). We applied the active ingredient at 3.36 $kg \cdot ha^{-1}$ on 26 May 2000 (~ 3 wk after planting) and at 7.84 $kg \cdot ha^{-1}$ on 13 Apr. 2001. The postemergence WMO was treatment with a selective grass herbicide, sethoxydim (2-{1-(ethoxyimino)butyl}-5-{2-(ethylthio)propyl}-3-hydroxy-2-cyclohexen-1-one) by backpack sprayer on 26 June 2000 and 2 July 2001. A 1.5% solution of the herbicide plus 1% by volume crop oil concentrate was applied

at 207 kPa. In addition, these plots were hand-weeded in late July through early August of each year.

To ensure that sufficient weed pressure would be present in at least one of the WMO in the study, the third group of WMO plots was inoculated by sowing the seeds of four problematic weed species. Nut sedge (*Cyperus dentatus*), narrow-leaved goldenrod *(Euthamia tenuifolia*), common flat-topped goldenrod (*E. graminifolia*), and switchgrass (*Panicum virgatum*) seeds were distributed uniformly within each plot on 23 May 2000 (19 d after cranberry vine planting). Sowing density was based on seed size as published by previous researchers (Burke and Grime, 1996). The grass seeds were sown at approximately 300 seeds•m^{-2}; all other seeds were sown at 550 seeds•m^{-2}. A fourth group of subplots received no treatment, and served as observation of natural recruitment and a reflection of no weed management efforts (untreated control).

Vegetation Surveys

Surveys of the vegetation present in each nitrogen/density/WMO were conducted on an annual basis. The survey dates for this study were: and 18 July and 30 July 2000, and 18 July, 23 July, and 3 Aug. 2001. Presence of each plant species in the 2-m^2 plot was estimated visually, using percentage estimate of coverage by the plant species. Adapted from other authors (Barbour et al., 1987; Kent and Coker, 1992), the following nine cover classes were used: <1%; 1-5%; 6-10%; 11-25%; 26-40%; 41-60%; 61-75%; 76-90%; and >90%.

Two observers recorded their estimations independently. Resolution of discrepancies, spaced by more than one group, was the average between the estimations. Resolution of discrepancies for adjacent groups was obtained by re-evaluation. Most species were identified in the field or brought to the lab for further inspection and identification through use of common flora (Newcomb, 1977; Gleason and Cronquist, 1991; Uva et al., 1997; Holmgren, 1998). Unknown species were sent to the UMass Herbarium and identified by Dr. Karen Searcy.

To facilitate analysis with the PC-ORD software (MjM Software Design, Gleneden Beach, OR), percentage cover (%Cover) ranges were assigned integer values (Table 2.14). Integer values are equivalent to cover class values (CCV). After analysis, data were converted back to %Cover values for presentation. Data were analyzed with PC-ORD to obtain species richness (number of species present) and the Shannon diversity index. The diversity index (Shannon and Weaver, 1949) is defined as:

$$H' = -\sum_{i=1}^{S} p_i \log p_i \qquad \text{(Equation 4.1)}$$

where S = number of species and p_i = the proportion of individuals or the abundance of the *i*th species expressed as a proportion of total cover, and log = log $base_n$ (log_{10} is most commonly used, but other bases are acceptable).

Vegetation data were analyzed in three separate groupings: all plant species, weeds only, and cranberry only. To form the second grouping, cranberry coverage values were omitted from the data set, and the data were re-analyzed to evaluate changes in weed populations only. Forming the third grouping, cranberry cover class values were analyzed separately to evaluate treatment effect on the crop species.

To examine whether prevalence of any species differed with treatment, relative abundances were calculated for all plant species and weed species only. Relative abundance (RA) of plant species *i* was defined (McCune and Grace, 2002) as:

$$RA_i = \frac{CCV_i}{\Sigma CCV} \times 100 \qquad \text{(Equation 4.2)}$$

where *i* = values for the *i*th species.

Statistical Analyses

The experimental design for this study was a randomized-complete-block-split-split-plot design with nitrogen rate as the main plot, vine density as the subplot and weed management option (WMO) as the sub-subplot. Treatments were replicated four times within each level for a total of 256 experimental units.

ANOVA was used to test for treatment effects and interactions for all data. Model assumptions were tested through residual analyses (Bowley, 1995). SAS code including Proc GLM, Proc Plot, and Proc Univariate was used to calculate and plot the pattern of the residuals. The Shapiro-Wilk statistic was used to test if the error distribution departed from normality. Many parameters had to be transformed to meet model assumptions and are mentioned specifically in the beginning of each subsection in the Results and Discussion section. If no mention of transformation is noted, data met model assumptions without transformation. Analyses were performed on the transformed data and the means of the transformed data. To facilitate reader understanding, means were back-transformed to their original units for tabular and graphical presentation.

SAS Version 8.2 (SAS Institute, Inc., Cary, NC) was used as the statistical analysis software package. If year*treatment interactions were not significant ($P>0.05$), data from Year 1 and Year 2 were pooled for further analysis. Most parameters had significant year*treatment interactions, and these parameters were analyzed by each year. F tests for main treatment effects and year*treatment interactions (as well as other interactions) for this study are listed in Appendices C1 and C.2.

Computed means for analyzed parameters are presented in the tables, and treatment effects are presented in figures. Orthogonal polynomial contrasts were used to describe the best-fit relationships for significant continuous main effects and their interactions. Significant treatment levels that could be legitimately tested for best fit were determined by utilizing

partitioning of the sum of squares via SLICE option in SAS Proc Mixed. Significant noncontinuous main effects (i.e., WMO) were separated by Kramer-adjusted Tukey's HSD (P=0.05). Significant interactions with WMO were separated by pairwise comparisons utilizing a Bonferroni correction. Summary tables of F tests from significant orthogonal polynomial contrasts and interactions may be found in Appendix C.3.

Vegetation survey data were first analyzed using a multivariate software package, PC-ORD, Version 4.24 (MjM Software Design, Gleneden Beach, OR). This software was used to generate descriptive statistics and diversity measures including species richness and Shannon diversity index. These data were subsequently tested for conformity to ANOVA model assumptions as described above. Several parameters were transformed and analyzed in SAS, utilizing PROC MIXED to determine treatment effects. Means were back-transformed for presentation.

Abbreviations have been used periodically to simplify expression of treatment effects and their interactions. For the purposes of the subsequent discussion, the following abbreviations may be found in the text:

N = nitrogen rate	Zero-N = 0 $kg \cdot ha^{-1}$
D = vine density	Low-N = 28 $kg \cdot ha^{-1}$
WMO = weed management option	Med(ium)-N = 56 $kg \cdot ha^{-1}$
Pre = preemergence treatment	High-N = 112 $kg \cdot ha^{-1}$
Post = postemergence treatment	Zero-D = 0 $t \cdot ha^{-1}$
Inoc = inoculated treatment	Low-D = 1.8 $t \cdot ha^{-1}$
Unt = untreated control	Med(ium)-D = 3.6 $t \cdot ha^{-1}$
Y = year	High-D = 5.4 $t \cdot ha^{-1}$

Interactions are linked by an asterisk (*). Abbreviations for treatment combinations are listed by split-plot order when appropriate and separated by slashes, e.g. Low-N/Zero-D/Inoc.

Results and Discussion

Basic Descriptive Statistics: All Plant Species and Weeds Only

Vegetation data were analyzed by dividing the information into three separate groupings: all plant species, weeds only, and cranberry only. Percentage cover and Shannon's diversity index (all plant species) were transformed using arcsine-square root. Data from all other variables from the other groups met model assumptions without transformations.

All identified plant species, along with %frequency and maximum cover class value (CCV), documented over the course of the study are presented in Table 4.1. If known, common names were also included. Fifty-five different weed species were identified during the two years of the study. In Year 1, cranberry had the highest frequency of any species (75.8%; occurring in 194 of the 256 plots), followed by large crabgrass (*Digitaria sanguinalis* (L.) Scop.) (69.1%). *Cyperus dentatus* (nutsedge) appeared most frequently in Year 2 (89.5%), followed by cranberry (78.9%). Cranberry was detected in 10 more plots than expected (originally planted into only 192 experimental units). Notably, hairgrass (*Muhlenbergia capallaris* (Lam.) Trin.) was not detected in Year 1, but was present in 80.9% of the plots in Year 2; *Panicum* species were virtually absent in Year 1 and were present in 44.5% of the plots in Year 2. Other notable increases in frequency from Year 1 to Year 2 include: narrow-leaved goldenrod (*Euthamia tenuifolia* (Pursh) Nutt.) 34.8% in Year 1 to 78.1% in Year 2; Canada rush (*Juncus canadensis* J. Gay), 19.9% to 39.1%; and white violet (*Viola lanceolata* L.) 11.3% to 51.2%. Notable decreases included ticklegrass (*Agrostis hyemalis* (Walter) BSP) 46.1% to 3.1%, and pitchfork (*Bidens frondosa* L.) 39.1% to 3.9% occurrences. Most weed species had maximum CCV of 6 or below (60% coverage or less) except *E. tenuifolia* (CCV=7) and *M. capallaris* (CCV=9). The nine noted species above

(excluding cranberry) have been identified as problematic on cranberry bogs (Demoranville, 1984; Demoranville, 1986).

Although the following discussion is basically segregated into the three groupings, results were sometimes best explained by combining the "all plant species" and the "weeds only" components into the same paragraph.

All Plant Species

During the first two years, nitrogen rate and WMO interacted to affect %Cover (Table 4.2). Partitioning the sum of squares indicated significance among WMO levels at all N rates. Pre-WMO plots had lower %Cover than untreated and inoculated plots at all N rates (Figure 4.1), except for the Low-N/Inoc plots. Post-WMO plots had lower %Cover than inoculated and untreated plots at the Med-N and High-N rates. Inoculated and untreated plots had similar %Cover at all N rates. Pre- and postemergence plots had similar %Cover except at the Zero-N rate, where Pre-WMO plots had lower %Cover than Post-WMO plots.

Density affected %Cover in Year 1 for all plant species. Best-fit relationship was strongly linear with a weak cubic component (P=0.038); %Cover increased as vine density increased (Figure 4.2). %Cover can increase as vine density increases since it is related to CCV. In most cases, cranberry tended to have higher cover values as density increased and the number of species did not vary, so %Cover increased. Furthermore, cranberry can be designated as a significant contributor to this upward trend as %Cover decreased with increasing vine density when only weeds were considered. Although this particular figure shows data from Year 2, density was significant overall (D*Y significant, so data were sorted by year) and was indicative of the overall trend for the first two years combined.

In Year 2, species richness, or the number of species, (Table 4.3) varied with vine density. Orthogonal polynomial contrasts indicated significant linear and cubic components. The number of species (all plant species considered) was lowest in the medium-D plots, 4.3

species•m^{-2} (Figure 4.3); the highest was in the Zero-D plots with 5.1 species•m^{-2}. Species richness, considering only weeds (Table 4.4), followed a similar trend with significant linear and quadratic components. Similar to the results with all plant species, medium-D plots had the lowest number of species with 3.8 species•m^{-2}, and Zero-D plots had the highest number with 5.0 species•m^{-2} (Figure 4.3).

Shannon diversity index (H′) was affected by WMO in Year 1 for all plant species (Table 4.5). Means were separated by Kramer-adjusted Tukey's HSD (Figure 4.4). Plots treated Pre-WMO had a lower diversity index (H′=1.30) than Post-WMO, Inoc-WMO, and Unt-WMO plots. The indices for these treatments ranged between 1.56 and 1.66. No other treatment effects were noted for diversity index. Pre-WMO plots trended towards a nondiverse community (cranberry dominated). Indices for Shannon's diversity typically range from 1.5 to 3.5, so the values in this study were at the lower end of the range (Kent and Coker, 1992). Since this was an agricultural study and an artificial community (we planted an abundance of one species), these are not unexpected values. Even though treatment effects can be seen, any interpretation of the biological importance of these statistical differences should be made cautiously.

Weed species only

During the first two years, nitrogen rate and WMO interacted to affect %Cover for weeds only (Table 4.6). Partitioning of the sum of squares indicated significance among WMO levels at all rates of nitrogen. All treatments were statistically similar at the Zero-N rate. Pre-WMO plots had a lower %Cover than untreated and inoculated plots at all other N rates (Figure 4.5). Post-WMO plots had lower %Cover than inoculated and untreated plots at the medium-N and High-N rate. Inoculated and untreated plots had similar %Cover at all N rates; Pre-WMO and Post-WMO plots had similar %Cover at all N rates.

The effect of WMO on Shannon's diversity index for weeds only (Table 4.7) varied with nitrogen during the first two years (Figure 4.6). Values ranged from 1.23 to 1.92 for the

N*WMO two-way combinations. Partitioning of the sum of squares for the N*WMO interaction indicated significance among WMO levels for High-N rates. Both Pre-WMO and Post-WMO had lower diversity indices than the untreated plots at the high N rate. As mentioned above, since these values fall in the low-end range when compared to other plant communities, the overall biological significance of statistical treatment differences should be interpreted cautiously.

Overall trends for 'All plant species' and 'Weeds only' survey

Pre-WMO and Post-WMO had less overall ground coverage of weeds and of all plants than inoculated and untreated plots. However, when the ground was occupied by vegetation in these WMO, it was mostly cranberry. By the end of Year 2, %Total (percentage cranberry of total plant biomass) values ranged from 74% to 99% (Table 3.12) in the Pre-WMO and Post-WMO plots; values dropped into the range from 35% to 83% in the Inoc-WMO and Unt-WMO plots. Species richness was not affected by nitrogen rate and varied slightly across vine densities, with the medium-D plots containing the fewest number of species. Nitrogen rate and vine density had minimal impact on Shannon's diversity index. The least diverse community was found in the Pre-WMO plots.

Treatment Effects on Cranberry Coverage

F tests for percentage cranberry cover are in Appendices C.1 and C.3. Mean cover class (integer) values were generated (Table 4.8) by converting percentage coverage values for cranberry only to cover class values (Table 2.14). Data were analyzed to evaluate the effect of treatment on the crop species. Data were fit to model assumptions without transformation.

Vine density and WMO affected cranberry coverage values in Year 1. Best-fit relationship for vine density had significant linear, quadratic, and cubic components. CCV increased as vine density increased, but to a lesser extent at the higher densities (Figure 4.7). To

estimate percentage ground cover based on mean CCV (integer values), the mid-point of each cover class range (percentage), y, was plotted against the cover class (integer) value, x. The best-fit relationship was the second-order polynomial equation,

$$y = 1.21x^2 - 0.44x \quad (R^2 = 0.99) \qquad \text{(Equation 4.3)}$$

(generated in Microsoft® Excel). The following % coverage estimates were calculated based on mean CCV. Vines planted in a low density had achieved approximately 14.9% coverage with a CCV of 3.58 (across all nitrogen rates). Medium-D plots had approximately 28.0% coverage (CCV=4.58) and High-D plots had 33.6% vine coverage (CCV=4.95; Figure 4.7). Inoculated plots had the lowest cranberry coverage (8.4%) compared to any other WMO (Figure 4.8). The maximum coverage for any WMO by the end of the first year was in the Pre-WMO plots with 14.7%.

In Year 2, the effect of WMO on cranberry coverage values varied with both nitrogen rate and vine density. Partitioning of the sum of squares for the N*WMO and D*WMO interactions indicated significance among WMO for the low, medium, and high N rates as well as the low, medium, and high D rates. At the three nitrogen rates, cranberry coverage was higher in Pre-WMO and Post-WMO compared to Inoc-WMO and Unt-WMO plots (Figure 4.9). In general, cranberry coverage was higher in Pre-WMO and Post-WMO when compared to Inoc-WMO and Unt-WMO plots at the three density levels (Figure 4.10). However, the Post-WMO plots (85% coverage), were only marginally different (P=0.009; cut-off for significance P=0.008) from the Inoc-WMO and the Unt-WMO at High-D; cranberry coverage in Pre-WMO (86%) was statistically higher than the Inoc-WMO and Unt-WMO (73% coverage).

The effect of vine density on cranberry coverage also varied with nitrogen rate in Year 2 (Figure 4.11). Partitioning of the sum of squares for the N*D interaction indicated significance among vine density for all nitrogen rates in Year 2. The best-fit relationship had significant

linear, quadratic, and cubic components at all nitrogen levels. Adding nitrogen at any vine density increased coverage of the bog surface by cranberry. At Zero-N and Low-N, cranberry coverage increased as density increased. At Med-N and High-N, planting at densities greater than 1.8 $t \cdot ha^{-1}$ did not increase cranberry coverage. At low vine densities, the highest cranberry coverage was approximately 58% in medium-N and High-N plots (Figure 4.11). At medium vine densities, coverage was directly related to N rate (45%, 64%, 77%, and 87%, respectively). Cranberry coverage in High-D plots at Low-N, Med-N, and High-N rates was very similar (88%, 82%, and 89%, respectively).

Nitrogen rate, vine density, and WMO and their interactions affected cranberry coverage. Weed control substantially increased cranberry coverage in almost all treatment combinations. Cranberry treated with the preemergence herbicide was equally efficient at colonizing the bog surface as cranberry that received postemergence strategies. Increased doses of N did not increase cranberry coverage at High-D plantings. By the end of Year 2, the following 2-way treatment combinations had estimated values (Equation. 4.3) of at least 80% cranberry coverage: High-N/High-D (89%), Low-N/High-D (88%), High-N/Med-D (87%), High-D/Pre (86%), High-D/Post (85%), and Med-N/High-D (82%).

Dominant Species and Relative Abundance

To further examine the effect of treatments on plant community composition, dominant species characteristics by nitrogen rate, vine density, and WMO were determined (Tables 4.9, 4.10, and 4.11, respectively). Within each treatment, the 10 most frequent species, with their respective %Cover values are listed. If an infrequent species had a high %Cover, it was included at the bottom of the list. Percentage frequency (%F) and %Cover are listed for Years 1 and 2.

The greatest number of species was identified in Med-N plots (n=19), followed by the Low-N plots (n=18) and Low-D and Unt-WMO (n=17). The fewest number of species were

found in the Zero-N plots (n=10) followed by the Post-WMO (n=12). In general, the two most abundant weed species were *Digitaria sanguinalis* and *Agrostis hyemalis* in Year 1 (Tables 4.9, 4.10, and 4.11). Both became less abundant in Year 2, surpassed by *Cyperus dentatus*, *Muhlenbergia capallaris*, and *Euthamia tenuifolia.* These three weeds have been identified as problematic on cranberry bogs (Demoranville, 1984; Demoranville, 1986). *Linaria canadensis* (Year 1) and *Hypericum* sp. (Year 2) were also relatively abundant for many treatments. Even though the particular number and type of species identified for each treatment level differed somewhat, these seven species were consistently the most prominent weeds detected during the course of the study.

Within the Year 1 nitrogen treatments (Table 4.9), *D. sanguinalis* was detected in 66% to 72% of the plots in the various nitrogen treatments, and *C. dentatus* peaked at 69% in High-N. In Year 2, *C. dentatus* was peaked at 95% frequency in High-N; *M. capallaris* was detected in 77% to 83% of the plots; and *E. tenuifolia* was detected at a maximum frequency of 86% in Med-N. Second only to cranberry, *M. capallaris* averaged 26% and 36% coverage in the Med-N and High-N plots, respectively, in Year 2.

Within density treatments in Year 1 (Table 4.10), *C. dentatus* occurred in 52% and 67% of the plots, and *D. sanguinalis* was detected in between 67% and 73% of the plots in the various density treatments. In Year 2, *C. dentatus* was detected at a frequency of at least 86% in the density treatments; *M. capallaris* occurred in at least 78% of the plots; and *E. tenuifolia* was detected in at least 76% of the plots. *M. capallaris* averaged 34% cover in the Zero-D plots and *C. dentatus* averaged 21% cover in the Low-D plots.

In Year 1, *C. dentatus* was not prevalent in Pre-WMO (28% frequency), but occurred in at least 64% of the other WMO treatments (Table 4.11). In Year 2, *C. dentatus* occurred in at least 83% of the WMO treatments. However, it never achieved more than 10% coverage in any Pre-WMO plot and averaged <1% cover overall for that WMO. In Year 1, *D. sanguinalis* was prevalent in Pre-WMO (75% frequency), Inoc-WMO (98% frequency), and Unt-WMO (97%

frequency), but absent in Post-WMO. Occurrences of *D. sanguinalis* dropped to 34% or less in Year 2. *M. capallaris*, not detected in Year 1, occurred in 55% of the Pre-WMO plots and in almost all of the Inoc-WMO and Unt-WMO plots (92% to 98%, respectively) in Year 2. *E. tenuifolia* was detected most often in Year 2 in the Inoc-WMO (92%), but still quite prevalent at its lowest occurrence in the Post-WMO (69%). Other notables in Year 1 included 50% frequency of *B. frondosa* in Post-WMO, 50% frequency of *L. canadensis* in Inoc-WMO and Unt-WMO; Year 2 included 73% frequency of *Hypericum* sp. in Pre-WMO, 64% frequency of *V. lanceolata*, 62% frequency of *Hypericum* sp., and 61% frequency of *J. canadensis* in Post-WMO.

Relative abundances values (Equation 4.2) were used to examine whether prevalence of any species differed with treatment. Species with RA greater than 5.0% in either Year 1 or Year 2 were included. RA values for all plant species were determined within the treatments of nitrogen rate, vine density, and WMO (Tables 4.12, 4.13, and 4.14, respectively). RA values for 'weeds only' were sorted by nitrogen rate, vine density, and WMO (Tables 4.15, 4.16, and 4.17, respectively).

Relative abundance - All plant species

D. sanguinalis was the most prevalent weed species across all nitrogen treatments in Year 1 (Figure 4.12). Conversely, its RA did not exceed 4.2 in Year 2 (Table 4.12). In Year 1, *Bidens frondosa* was abundant in Med-N plots, *Ambrosia artemisiifolia* is abundant in Low-N plots, and *L. canadensis* was abundant at both of these N rates. Cranberry was most abundant at all N rates, peaking in the Zero-N and High-N plots (Figure 4.12). *M. capallaris*, which was barely present in Year 1, was the most prevalent weed species across all N treatments in Year 2 (Figure 4.12). *E. tenuifolia* was abundant at all N rates in Year 2; *Panicum* sp. were only abundant in High-N plots. *Hypericum* sp. were abundant at Zero-N and Low-N rates. *A. hyemalis*, *B. frondosa* and *L.*

canadensis became much less abundant in Year 2 (RA ≤0.5). The relative abundance of cranberry became more stable across N treatments by the end of two years of growth.

Similar patterns can be seen when RA are examined by vine density treatment. In Year 1, *B. frondosa* was abundant in the High-D plots, but became virtually nonexistent in Year 2 (Figure 4.13 and Table 4.13). *L. canadensis*, abundant at Zero-D and Low-D plots in Year 1, also became much less abundant in Year 2. *Viola lanceolata*, *Panicum* sp. and *Hypericum* sp., all marginally present in Year 1, were abundant in the Zero-D plots in the second year of growth. RA values for *E. tenuifolia* ranged between 2.5 and 4.5 in Year 1, but by the end of Year 2, it was abundant at all vine densities.

Evaluation of the WMO treatments indicated *E. tenuifolia* was present (2.7 to 4.6) in all WMO treatments in Year 1 and abundant in Year 2 (Figure 4.14 and Table 4.14). *B. frondosa* was abundant in the Post-WMO plots in Year 1, but rarely detected in Year 2. *A. hyemalis*, abundant in the untreated and inoculated plots in Year 1, was barely detectable in Year 2. *D. sanguinalis* was very abundant in Year 1, but never exceeded 5% RA in Year 2. *C. dentatus* was abundant in both years in all WMO except Pre-WMO in Year 1. *Juncus canadensis* had RA = 5.1% in Year 2 in the Post-WMO. Grasses in the WMO plots were primarily represented by *M. capallaris* and *Panicum* sp. in Year 2.

Relative abundance – Weed species only

When cranberry was omitted from the list of species, several weed species previously listed under the 5% level, exceeded this RA value (Tables 4.15, 4.16, and 4.17) for some treatment combinations. For example, *E. tenuifolia* had RA = 4.5 in Year 1 in the medium density with all plant species included (Table 4.13). When only weed species were examined, its RA increased to 6.9 (Table 4.16). Similarly, *Hypericum* sp. had an RA value of 3.8 in the Pre-WMO with cranberry (Table 4.14) that changed to a value of 6.8 when cranberry was omitted

(Table 4.17). Two species that were not even previously noted attained RA values >5%: *Spergularia rubrum* and *Cyperus strigosus*.

Even though the species lists from various treatment combinations varied somewhat when compared to each other, the same central group of weed species (by subjective deduction) was considered abundant over the course of the project:

Agrostis hyemalis (Y1)
Ambrosia artemisiifolia (Y1)
Bidens frondosa (Y1)
Cyperus dentatus (Y1 & Y2)
Digitaria sanguinalis (Y1)
Euthamia tenuifolia (Y1 and Y2)
Hypericum sp. (Y2)
Linaria canadensis (Y1)
Muhlenbergia capallaris (Y2)
Panicum sp. (Y2)

All of these plant species are considered at least moderately problematic on cranberry bogs with the exception of *L. canadensis* and *Hypericum* sp. (Demoranville, 1984; Demoranville, 1986; Sandler, 2003).

The specific plant community composition that would establish in a newly planted area is likely to be different for any given location. The phenomenon of a bog system having a unique pest complex has been documented for other cranberry pests (Averill and Sylvia, 1998; Caruso, 1998; Caruso et al., 2000). However, the potential of site-to-site variation in species composition (insects, pathogens, or weeds) does not discount the importance of the general observations made during research studies. The identification of biological trends from individual research projects have been successfully extended to the cranberry industry and incorporated into the development of pest management strategies (DeMoranville, 1992; Averill et al., 1994; Sandler et al., 1997).

Much of the work examining the relationship of weed flora to integrated crop management techniques follows community composition changes over long periods of time, (Zanin et al., 1997; Anderson et al., 1998; Andersson and Milberg, 1998). However, some recent publications have documented the effect of integrated crop management practices over shorter

time periods, such as 3 years (O'Donovan et al., 1997; Barberi and Mazzoncini, 2001). Few, if any, research projects (excluding those investigating the use of herbicides only) have investigated the effect of ICM on weed flora in perennial crops. Thus, results presented in this study represent new information on the relationship of weed flora to various crop management practices in perennial fruit crop systems.

Cover Class Values and Cranberry Biomass

To estimate cranberry biomass that would be predicted from a particular cover class value, cranberry stem and total biomass values (y) for Year 1 and Year 2 were tested for the best-fit relationship with cover class values (x). Stem and total cranberry biomass gave similar trends. The best fits for cranberry total biomass (Figure 4.15) were quadratic relationships in Year 1 and Year 2 (R^2 = 0.66 and 0.76, respectively). For simplicity, only total cranberry biomass values are discussed, but observations may be extended to cranberry stem biomass.

Estimates of plant cover are often used by growers to rate the progress of the planting. Collection of biomass samples are not used by growers because vine removal is very destructive, and processing the sample is very time-consuming. In this study however, both visual estimates and cranberry biomass data were collected from for each treatment combination. This information was used to assess the relative success of specific combinations in terms of cranberry biomass production.

Cranberry biomass production by two-way treatment combination

Two-way treatment combinations are depicted in a grid display, color-coded for six cover class groupings (Figures 4.16 through 4.20). Simplifying for illustrative purposes, the 9 percentage cover ranges (or CCV) used in the field (Table 2.14) were consolidated into 5 ranges by combining neighboring groups (e.g., CCV of 0, 1, and 2 were combined to give a grouping

that indicated vine coverage of 0% to 5%; CCV of 3 and 4 were combined to approximate vine coverage of 6% to 25%, etc.). An extra group, predicted cranberry biomass that would represent vine overgrowth (i.e., elongated upright growth and lengthy runners) (Chandler, 1961; Eck, 1971; Eck, 1976) was coded as 'excessive'. A set of predicted biomass ranges (Table 4.18) was calculated, based on the best-fit second-order polynomial equations,

$$\text{Year 1: } y = 4.13x^2 + 32.19x + 0.90 \quad (R^2 = 0.66) \qquad \text{(Equation 4.4)}$$

$$\text{Year 2: } y = 7.63x^2 + 20.74x + 3.11 \quad (R^2 = 0.76) \qquad \text{(Equation 4.5)}$$

Each range was assigned a different color code (Figures 4.16 to 4.20). For informational purposes, the maximum predicted biomass value ($g \cdot m^{-2}$) for each cover class grouping was written within one box for each color code. The actual mean biomass values for each 2-way combination (Table 3.10) were then assigned to a color code based on the ranges established by the predicted values.

In Year 1, no N*D combination achieved more than 60% vine coverage. Zero-D plots at any nitrogen level had a predicted biomass of less than 80.6 $g \cdot m^{-2}$ and had $\leq$5% coverage (Figure 4.16). Actual values were less than 0.3 $g \cdot m^{-2}$. Zero-N/Low-D, Low-N/Low-D, Med-N/Low-D and Zero-N/Med-D plots had similar biomass values, producing between 105 and 180 $g \cdot m^{-2}$. All other medium-D plots and all High-D plots produced between 202 and 319 $g \cdot m^{-2}$.

By the end of Year 2, differences in N*D combinations became more pronounced. Zero-D plots at any nitrogen level had a predicted biomass of less than 71.8 $g \cdot m^{-2}$ and still had $\leq$5% coverage. Actual values ranged between 0 and 7.8 $g \cdot m^{-2}$. Zero-N/Low-D did not exceed 25% coverage, producing 179 $g \cdot m^{-2}$. Low-N/Low-D, Zero-N/Med-D, and Zero-N/High-D produced similar amounts of biomass, having between 26% to 60% coverage and producing between 262 to 332 $g \cdot m^{-2}$. The next similar group of N*D combinations were Low-N/Med-D, Low-N/High-D, Med-N/Low-D and High-N/Low-D, producing between 523 to 590 $g \cdot m^{-2}$ and having 61% to 90%

coverage. Med-N/Med-D and Med-N/High-D produced biomass equivalent to 100% vine coverage, producing 679 and 737 $g \cdot m^{-2}$, respectively. High-N/Med-D and High-H/High-D produced excessive vine biomass, 817 and 844 $g \cdot m^{-2}$, respectively.

Examination of the effect of N*WMO on cranberry biomass production (Figure 4.17) indicated that most combinations had between 6% to 25% coverage by the end of Year 1, producing between 119 to 191 $g \cdot m^{-2}$. Low-N/Pre, High-N/Pre and Post-WMO (all N rates except zero) had between 26% to 60% coverage with total cranberry biomass production ranging from 203 to 253 $g \cdot m^{-2}$.

Treatments differences became more apparent in Year 2. Zero-N plots (across all densities) had less than 25% vine cover (produced between 185 and 205 $g \cdot m^{-2}$). Low-N/Post, Low-N/Inoc, and Low-N/Unt produced less biomass (310 to 364 $g \cdot m^{-2}$) than Low-N/Pre, which produced 420 $g \cdot m^{-2}$ and was placed into the next coverage category (61% to 90%). All Med-N/WMO combinations had between 61% to 90% coverage and produced between 456 to 612 $g \cdot m^{-2}$, except for the Med-N/Inoc, which fell in the 25% to 60% category and produced 365 $g \cdot m^{-2}$. High-N/Unt and High-N/Post combinations had between 61% to 90% coverage and produced between 524 to 616 $g \cdot m^{-2}$, respectively. High-N/Inoc had slightly less than 60% coverage and produced 399 $g \cdot m^{-2}$, while the High-N/Pre was placed in the 91% to 100% category and produced 681 $g \cdot m^{-2}$. At Low-N and High-N rates, the Pre-WMO plots produced more cranberry biomass than the other WMO treatments.

The interaction of density and WMO indicated that, in both years, Zero-D plots produced less than 5% vine coverage (Figure 4.18). Actual biomass production was less than 4.3 $g \cdot m^{-2}$. In Year 1, all Low-D/WMO combinations and Med-D/Inoc were in the 6% to 25% coverage category and produced 110 to 195 $g \cdot m^{-2}$. The other combinations never covered more than 60% of the surface and produced 217 to 323 $g \cdot m^{-2}$. By the end of Year 2, coverage was better in the Pre-WMO and Post-WMO plots than the untreated and inoculated plots within any particular density level (except zero). At Low-D and High-D, Pre-WMO and Post-WMO were in a higher

coverage category and produced more biomass (Low-D: 501 and 444 g•m^{-2}, respectively, and High-D: 697 and 671 g•m^{-2}, respectively) than the Inoc-WMO and the Unt-WMO (Low-D: 278 and 380 g•m^{-2}, respectively, and High-D: 532 and 602 g•m^{-2}). At the Med-D, the Pre-WMO produced more biomass (695 g•m^{-2}) and fell in a higher category than the other WMO combinations. Even though the Med-D/Post fell in a similar coverage category as the Med-D/Inoc and Med-D/Unt, its biomass production was at the high end of the 401 to 657 g•m^{-2} range (actual value = 621 g•m^{-2}) while the biomass for the other combinations fell squarely in the mid-range of the category with values of 447 and 519 g•m^{-2}, respectively.

Cranberry biomass production by three-way treatment combination

By the end of Year 1, 5 three-way combinations had the best vine growth, attaining 61% to 90% coverage: Med-N/Med-D/Post (455 g•m^{-2}), Low-N/High-D/Pre (418 g•m^{-2}), Low-N/High-D/Post (386 g•m^{-2}), Med-N/High-D/Post (372 g•m^{-2}), and High-N/High-D/Pre (358 g•m^{-2}) (Figure 4.19, Table 3.10). Across WMO (excluding the three-way combinations just mentioned), Low-N/Med-D combinations produced approximately equivalent amounts of cranberry biomass (185 to 284 g•m^{-2}) as the Med-N/Med-D (237 to 327 g•m^{-2}) and High-N/Med-D plots (155 to 314 g•m^{-2}). Biomass production was lowest (excluding Zero-D plots) in the Zero-N/Low-D/Unt (71 g•m^{-2}), followed by Low-N/Low-D/Unt (91 g•m^{-2}), and Med-N/Low-D/Unt (105 g•m^{-2}).

By the end of Year 2, Zero-N plots at all densities and the Low-N/Low-D plots still had less than 60% ground cover (Figure 4.20). Low-N plots at medium and high densities had good vine coverage (61% to 100%). Although the Low-N/Med-D/Pre produced the most biomass in the Low-N group (672 g•m^{-2}), overall, no improvement was gained by planting vines at 5.4 t•ha^{-1} rather than 3.6 t•ha^{-1} when low rates of nitrogen were added. Excessive vine growth (overgrowth of runner and upright length) (Chandler, 1961; Hart et al., 1990; DeMoranville, 1992) was seen for the Pre-WMO at medium and high vine densities that received either medium-N or High-N

rates. Vine overgrowth was also noted in the High-N/Med-D/Post and High-N/High-D/Post plots. Biomass production was highest in the High-N/High-D/Pre and High-N/Med-D/Pre (1,020 and 1,004 $g \cdot m^{-2}$, respectively).

Summarizing biomass production at the end of two years, at Low-N rates, planting vines at 5.4 $t \cdot ha^{-1}$ did not provide any additional benefit in coverage or cranberry biomass production than planting vines at 3.6 $t \cdot ha^{-1}$ for all WMO. The exception was improved performance in the Low-N/Medium-D/Pre treatment; these plots achieved 90% to 100% coverage and produced 672 $g \cdot m^{-2}$. Caution should be exercised when using Low-D and Low-N regimes; these plots only attained approximately 35% coverage (mean biomass of 302 $g \cdot m^{-2}$) by the end of two years.

Determination of Optimal Initial Vine Density

To determine the theoretical optimum planting density at each nitrogen rate, total cranberry biomass data were regressed with vine density. Data were examined in two groups: total cranberry biomass produced at the end of two years growth from all treatment combinations (Figure 4.21), and biomass from Pre-WMO and Post-WMO only (Figure 4.22). Since weed management positively affected cranberry biomass production, and weed control would be used during vine establishment, examination of these data alone seemed warranted. For all nitrogen rates, biomass production was best-fit to a quadratic relationship with vine density.

Using biomass values from all WMO, maximum biomass production (759 $g \cdot m^{-2}$) for Med-N combinations occurred with a planting density of 4.4 $t \cdot ha^{-1}$ (Figure 4.21). This biomass production gave just under 100% coverage. For High-N, maximum values exceeded 100% coverage and would be considered excessive. For this treatment, 100% coverage was achieved with an initial planting density of 3.4 $t \cdot ha^{-1}$. In commercial settings, achieving 90% coverage after 2 years would be a reasonable and desirable goal. Initial vine densities of 2.7 $t \cdot ha^{-1}$ and 2.3 $t \cdot ha^{-1}$ for the Med-N and High-N treatments would give 90% coverage. Zero-N and Low-N treatments did not attain 90% coverage for any density up to the maximum of 5.4 $t \cdot ha^{-1}$.

Maximum biomass production of 334 g•m^{-2} and 600 g•m^{-2} would occur at 6.3 t•ha^{-1} and 6.0 t•ha^{-1} for the Zero-N and Low-N treatments, respectively (Figure 4.21).

Using cranberry biomass data from the Pre-WMO and Post-WMO only gave similar patterns, but different optimal values (Figure 4.22). When used in conjunction with weed management, lower initial densities could produce substantial cranberry coverage in two years. Med-N and High-N weed control combinations achieved 100% coverage with initial planting densities of 2.6 and 2.5 t•ha^{-1} (vertical lines designate the predicted vine density values for Med-N and High-N) respectively (0.9 to 1.8 t•ha^{-1} less than when all WMO were combined). Moreover, both Med-N and High-N weed control combinations achieved 90% coverage with an initial planting density of 1.8 t•ha^{-1} (0.5 to 0.9 t•ha^{-1} less than all treatments were combined). For Med-N, cranberry biomass production started to decline at vine densities that exceeded 3.9 t•ha^{-1}. At its maximum, Low-N weed management combinations barely achieved 90% coverage with 5.2 t•ha^{-1} (634 g•m^{-2}); planting at this density would be cost-prohibitive for many growers. Zero-N combinations did not exceed 60% coverage; an initial planting density of 6.0 t•ha^{-1} would be needed to achieve the maximum biomass production of 324 g•m^{-2}.

In conclusion, growers could use low initial vine densities (1.8 t•ha^{-1}) with Med-N or High-N applications with a weed management program (either preemergence or postemergence) and expect to achieve 90% cranberry vine coverage after two years of growth. Use of an additional 0.5 to 1.0 t•ha^{-1} at planting could achieve 100% coverage at the end of two years, but would require at least $800 to $1,000•ha^{-1} as added initial costs.

Conclusions

Out of the 54 different species identified during the two-year study, *D. sanguinalis, C. dentatus, E. tenuifolia, A. hyemalis, B. frondosa, Hypericum* sp., *Panicum* sp., *A. artemisiifolia, L. canadensis, and M. capallaris* were the most prominent species. Most of these plant species are

considered to be problematic on cranberry bogs. Two other weeds, occasionally problematic in cranberry production, were noteworthy in abundance: *J. canadensis* and *C. strigosus*.

C. dentatus is a common weed problem on new plantings (personal observation). *C. dentatus* occurred frequently across all nitrogen and density treatments. Application of napropamide was effective in reducing the occurrence and spread of this weed in Year 1. Not detected in the first year of the planting, *M. capallaris* became extremely prevalent in all treatments in Year 2. This perennial grass may have missed detection as it forms a small rosette in the first year of its life cycle (Demoranville, 1986), and then produces its upright portions in the following year. *E. tenuifolia* was also detected frequently across all nitrogen and density treatments. WMO did not seem to impact the occurrence of this weed, however Post-WMO had lower %Cover and maximum CCV compared to Pre-WMO. This plant species is considered to be a serious pest on established commercial cranberry farms (Else et al., 1995). Napropamide suppressed *E. tenuifolia* populations in Year 1, but other weed control must be used to manage this weed in subsequent years.

The specific progression and composition of the plant community noted in this research study would not likely be repeated during the vine establishment process at other cranberry farms. However, the potential of site-to-site variation in plant species composition does not discount the importance of the general treatment effects noted in this study. Pre-WMO and Post-WMO were equally effective at reducing %Cover compared to inoculated and untreated plots. Increasing the planting density of cranberry vines suppressed the spread and number of species richness in the weed community by the end of two years. Application of the preemergence herbicide, napropamide, significantly favored the development of a cranberry-dominated establishment across all vine densities and nitrogen rates. When N was highly abundant, weed control was essential to favor a cranberry-dominated community.

Although a few single treatment effects affected cranberry coverage, vine establishment was in fact most affected by treatment interactions. Weed management was critical across all

densities (except zero) and all nitrogen rates (except zero) to ensure good vine establishment. Pre-WMO and Post-WMO similarly improved cranberry coverage compared to Inoc-WMO and Unt-WMO. At Low-D, no additional benefit in cranberry coverage was gained by adding nitrogen at more than 56 $kg \cdot ha^{-1}$. At Med-D, cranberry coverage increased as nitrogen rate increased, and at High-D, all nitrogen rates (except zero) resulted in equivalent vine establishment. High-N/High-D, Low-N/High-D, and High-N/Med-D resulted in more than 87% cranberry coverage by the end of two years.

Five three-way combinations gave promising forecasts for cranberry establishment: Low-N/Med-D/Pre, Med-N/Low-D/Pre, Med-N/Low-D/Post, Med-N/Med-D/Post, and Med-N/High-D/Post. These treatments had substantial vine coverage (>89%), without excessive vine growth, and very good to excellent weed control (typically >80% weed reduction compared to untreated plots; see Chapter 3). Low-N/Low-D combinations attained only 35% coverage after two years, and would not be a recommended formula for commercial plantings. Several three-way combinations had good cranberry coverage, but would be considered unacceptable options due to poor weed control (>37% of the total biomass attributable to weeds).

Other weed scientists have acknowledged that the diversity of weed communities will determine the nature of weed management options and changes in weed diversity may present potential weed management problems (Derksen et al., 1995). IWM strategies can influence the composition of the weed flora in agricultural settings (Andersson and Milberg, 1998). In the current study, nitrogen, vine density, and WMO interacted to impact the composition, occurrence and coverage of weed species and cranberry in newly established plantings. Several treatment combinations offer reasonable formulas for attaining substantial cranberry vine coverage of the bare surface while minimizing weed establishment. Most farms will likely have different plant communities than the one described in this study. Thus, scouting should be employed to identify plant species to promote efficient weed management in new cranberry plantings.

Table 4.1. List of plant species identified at State Bog site, 2000-2001. Percentage frequency and maximum cover class per year are listed for each weed. nd=not detected.

Species name	Common name	Frequency (%)		Max CCV	
		Year 1	Year 2	Year 1	Year 2
Agrostis hyemalis	ticklegrass	46.1	3.1	4	2
Ambrosia artemisiifolia	common ragweed	25.8	42.6	4	6
Aster sp.	asters	11.7	29.3	2	3
Bidens frondosa	pitchfork	39.1	3.9	3	2
Bulbostylis capallaris		6.3	1.2	2	2
Carex sp.		3.1	17.6	2	3
Cuscuta gronovii	swamp dodder	0.4	6.3	2	2
Cyperus dentatus	nut sedge	62.1	89.5	3	6
Cyperus strigosus	false nut sedge	12.1	29.7	3	4
Digitaria ischaemum		4.7	nd	4	nd
Digitaria sanguinalis	large crabgrass	69.1	23.8	6	6
Eleocharis microcarpa		0.8	nd	1	nd
Epilobium angustifolium	fireweed	5.9	24.6	2	3
Eupatorium dubium	Joe-pye weed	3.1	7.0	1	3
Euthamia graminifolia	common goldenrod	3.5	21.9	2	2
Euthamia tenuifolia	narrow-leaved goldenrod	34.8	78.1	3	7
Hieracium sp.	hawkweed	nd	1.2	nd	2
Hypericum gentianoides	orangegrass	20.3	32.0	2	5
Hypericum mutilum	St. John's wort	9.4	nd	2	nd
Hypericum sp.	St. John's wort	22.7	59.8	2	5
Jasione montana	sheep's bit	nd	1.2	nd	2
Juncus bufonius	toad rush	0.4	nd	2	nd
Juncus canadensis	Canada rush	19.9	39.1	2	3
Juncus effusus	soft rush	nd	14.8	nd	4
Juncus tenuis	path rush	2.0	16.4	1	3
Kalmia angustifolia	sheep laurel	0.4	nd	3	nd
Leersia oryzoides	cut grass	0.4	nd	1	nd
Leontodon taraxacoides	little hawkbit	0.8	15.2	1	2
Linaria canadensis	toadflax	41.4	41.4	4	3
Ludwigia palustris	common water purslane	3.5	nd	2	nd
Lysimachia terrestris	yellow loosestrife	0.4	5.1	1	2
Mentha arvensis	field mint	nd	0.8	nd	2
Mollugo verticillata	carpetweed	15.6	nd	4	nd
Muhlenbergia capallaris	smokegrass	nd	80.9	nd	9
Panicum clandestinum	broad-leaved panicum	1.2	2.0	1	3
Panicum dichotomiflorum		0.8	1.2	2	2
Panicum sp.		nd	44.5	nd	6
Panicum virgatum	switchgrass	nd	2.3	nd	3

continued, next page

Table 4.1, continued

Pinus sp.	pine	nd	3.1	nd	1
Polygonum pensylvanicum	Pennsylvania smartweed	10.9	4.3	2	2
Polygonum persicaria	lady's thumb	5.5	2.3	3	2
Polytrichum commune	haircap moss	nd	9.8	nd	4
Prunus sp.		nd	0.4	nd	1
Quercus sp.	oak	nd	0.4	nd	2
Rhus radicans	meadow beauty	nd	8.6	nd	2
Rubus allegheniensis	upright bramble	nd	0.4	nd	2
Rumex acetosella	red sorrel	9.0	5.5	2	3
Salix sp.	willow	4.7	30.5	1	2
Scirpus cyperinus	woolgrass	nd	0.4	nd	2
Spergula sp.	spurrey	nd	0.4	nd	2
Spergularia rubrum	roadside sand-spurrey	21.1	12.1	3	4
Triadenum virginicum	marsh St. john's wort	0.8	9.0	1	2
Vaccinium macrocarpon	American cranberry	75.8	78.9	7	9
Viola lanceolata	white violet	11.3	51.2	4	4

Table 4.2. All plant species. Percentage cover from vegetation surveys for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cover[z]		
			Year 1	Year 2	Mean
0	0	Pre	0.1	13.3	6.7
		Post	0.1	34.3	17.2
		Inoc	0.1	19.4	9.7
		Unt	0.9	27.8	13.9
	1.8	Pre	1.6	14.8	8.2
		Post	6.9	26.1	16.5
		Inoc	2.4	25.2	13.8
		Unt	7.5	17.8	12.7
	3.6	Pre	0.1	13.3	6.7
		Post	3.8	18.6	11.2
		Inoc	11.3	22.6	17.0
		Unt	8.7	29.6	19.2
	5.4	Pre	5.8	20.2	13.0
		Post	10.0	34.3	22.1
		Inoc	8.1	28.7	18.4
		Unt	11.3	27.0	19.1
28	0	Pre	4.8	40.0	22.4
		Post	9.3	46.9	28.1
		Inoc	8.7	56.0	32.4
		Unt	10.0	56.0	33.0
	1.8	Pre	10.0	47.9	28.9
		Post	14.1	44.9	29.5
		Inoc	26.1	50.9	38.5
		Unt	24.3	62.1	43.2
	3.6	Pre	10.6	44.9	27.8
		Post	10.6	55.0	32.8
		Inoc	10.6	48.9	29.8
		Unt	17.8	56.0	36.9
	5.4	Pre	11.9	40.0	26.0
		Post	13.3	36.1	24.7
		Inoc	24.3	69.2	46.8
		Unt	30.5	64.1	47.3

continued, next page

Table 4.2, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cover		
			Year 1	Year 2	Mean
56	0	Pre	2.0	61.1	31.5
		Post	5.8	66.2	36.0
		Inoc	5.8	79.1	42.5
		Unt	4.3	49.9	27.1
	1.8	Pre	10.0	61.1	35.5
		Post	8.7	54.0	31.3
		Inoc	16.3	75.2	45.7
		Unt	40.0	83.9	62.0
	3.6	Pre	4.8	38.1	21.4
		Post	11.9	51.9	31.9
		Inoc	24.3	58.0	41.2
		Unt	27.8	59.1	43.4
	5.4	Pre	32.4	55.0	43.7
		Post	23.5	57.0	40.3
		Inoc	49.9	83.0	66.4
		Unt	43.9	79.1	61.5
112	0	Pre	0.1	38.1	19.1
		Post	0.8	64.1	32.5
		Inoc	4.8	62.1	33.4
		Unt	15.5	83.9	49.7
	1.8	Pre	2.9	56.0	29.4
		Post	4.8	74.2	39.5
		Inoc	13.3	66.2	39.8
		Unt	17.0	82.0	49.5
	3.6	Pre	5.3	36.1	20.7
		Post	6.9	45.9	26.4
		Inoc	15.5	74.2	44.9
		Unt	32.4	77.2	54.8
	5.4	Pre	11.3	46.9	29.1
		Post	6.4	53.0	29.7
		Inoc	17.0	69.2	43.1
		Unt	21.0	86.7	53.9

[z]N*W affected percentage cover ($P=0.045$) during the first two years.
Density affected percentage cover ($P<0.001$) in Year 1.

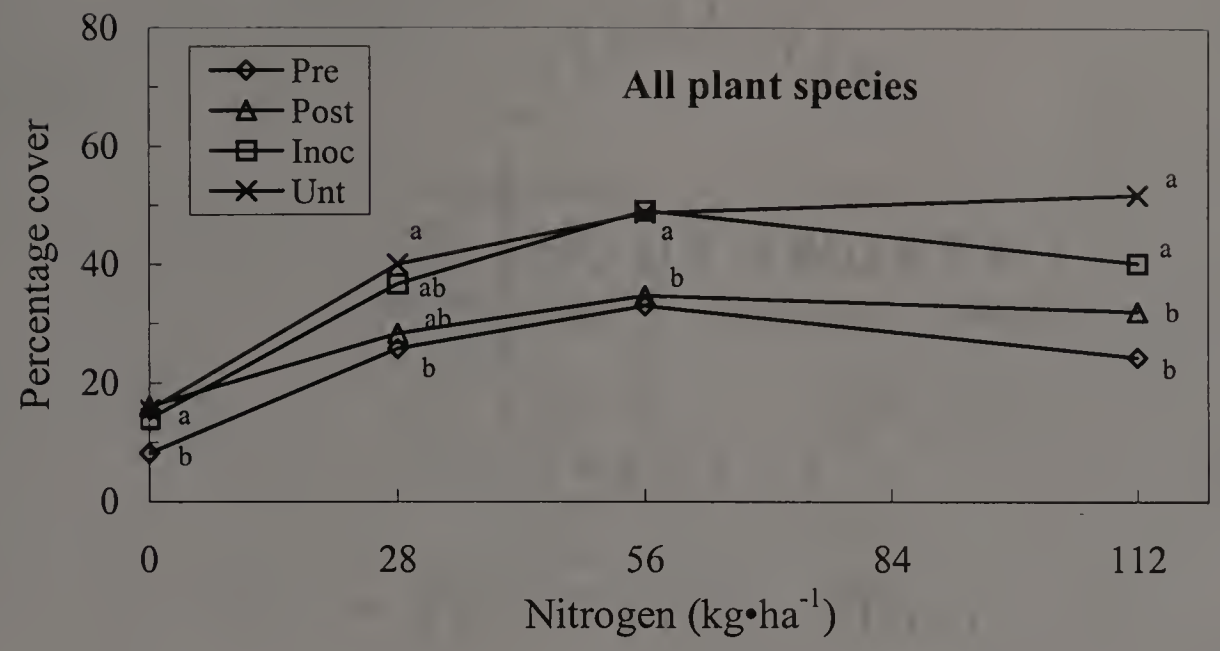

Figure 4.1. All plant species. Interaction of nitrogen rate and WMO on percentage cover during the first two years (N=32). Significant differences among WMO occurred at all N rates. Means, within each N level, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

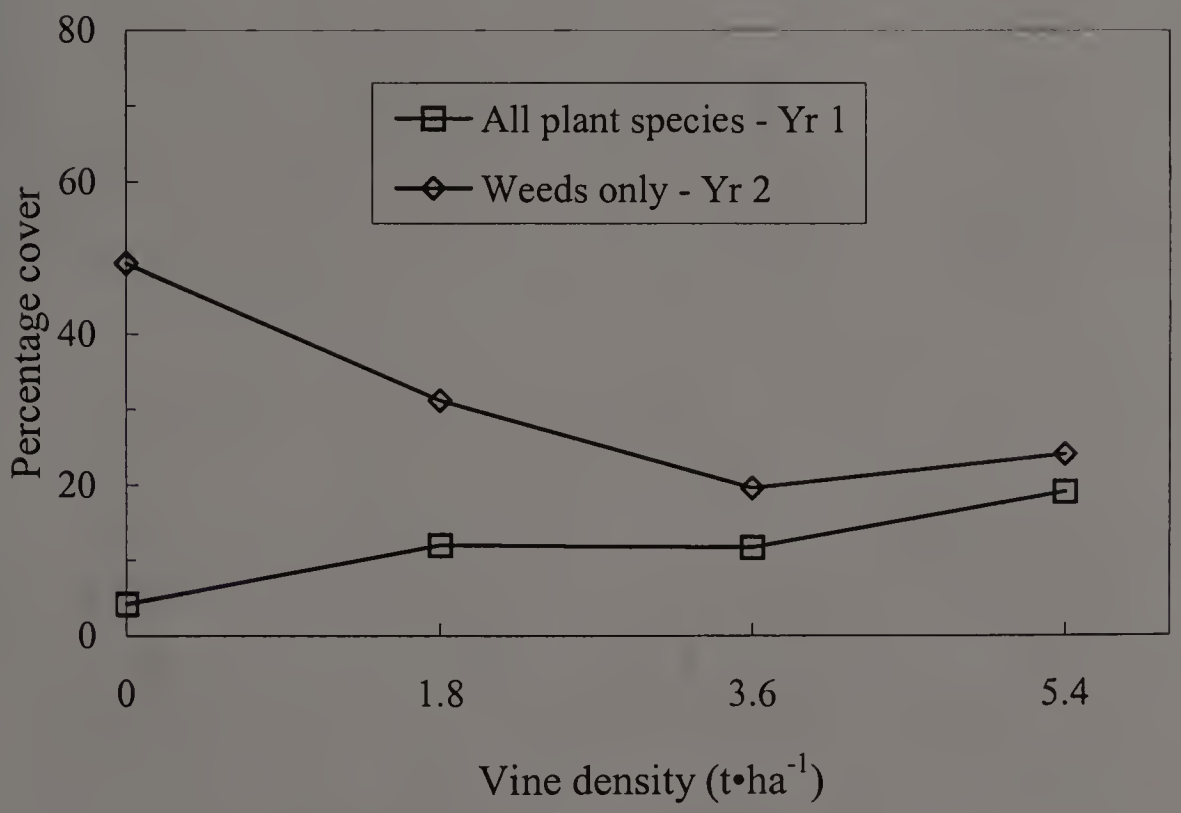

Figure 4.2. Effect of vine density on percentage cover of all plant species (Year 1) and weeds only in Year 2 (N=64).

Table 4.3. All plant species. Species richness of vegetation surveys for all weed management option plots (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Species richness - All plant species[z] (no. species$\cdot m^{-2}$) Year 1	Year 2	Mean
0	0	Pre	1.38	4.00	2.69
		Post	2.63	5.13	3.88
		Inoc	1.50	4.25	2.88
		Unt	2.13	4.38	3.25
	1.8	Pre	2.25	3.75	3.00
		Post	3.38	4.63	4.00
		Inoc	2.25	4.25	3.25
		Unt	2.88	3.63	3.25
	3.6	Pre	1.38	3.00	2.19
		Post	2.63	3.63	3.13
		Inoc	2.88	3.38	3.13
		Unt	2.75	3.88	3.31
	5.4	Pre	2.38	3.38	2.88
		Post	3.38	4.75	4.06
		Inoc	2.38	3.75	3.06
		Unt	2.50	3.50	3.00
28	0	Pre	3.25	5.00	4.13
		Post	3.88	5.88	4.88
		Inoc	3.00	5.75	4.38
		Unt	3.50	5.13	4.31
	1.8	Pre	3.13	5.13	4.13
		Post	3.63	4.75	4.19
		Inoc	4.38	5.00	4.69
		Unt	4.25	5.75	5.00
	3.6	Pre	3.13	4.75	3.94
		Post	3.25	5.38	4.31
		Inoc	2.88	4.88	3.88
		Unt	3.50	5.00	4.25
	5.4	Pre	3.00	4.38	3.69
		Post	3.25	4.00	3.63
		Inoc	3.88	6.13	5.00
		Unt	4.50	5.25	4.88

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Table 4.3, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Species richness - All plant species (no. species$\cdot m^{-2}$) Year 1	Year 2	Mean
56	0	Pre	3.00	6.00	4.50
		Post	3.88	6.00	4.94
		Inoc	3.13	5.75	4.44
		Unt	2.75	4.50	3.63
	1.8	Pre	3.50	5.63	4.56
		Post	3.00	4.75	3.88
		Inoc	3.13	5.38	4.25
		Unt	4.13	6.50	5.31
	3.6	Pre	2.38	4.00	3.19
		Post	3.88	4.63	4.25
		Inoc	3.75	4.50	4.13
		Unt	3.88	4.63	4.25
	5.4	Pre	4.13	5.00	4.56
		Post	4.25	5.13	4.69
		Inoc	4.88	5.38	5.13
		Unt	4.13	5.38	4.75
112	0	Pre	2.00	4.50	3.25
		Post	2.88	5.25	4.06
		Inoc	2.25	4.63	3.44
		Unt	3.25	5.88	4.56
	1.8	Pre	2.13	4.75	3.44
		Post	2.38	5.50	3.94
		Inoc	3.00	4.75	3.88
		Unt	3.38	6.13	4.75
	3.6	Pre	2.25	3.50	2.88
		Post	2.50	3.50	3.00
		Inoc	2.63	4.63	3.63
		Unt	4.25	5.00	4.63
	5.4	Pre	2.75	4.13	3.44
		Post	2.38	4.38	3.38
		Inoc	3.00	4.38	3.69
		Unt	2.50	5.75	4.13

[z]In Year 2, density affected species richness (P=0.010).

Table 4.4. Weed species only. Species richness of vegetation surveys for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Species richness - Weeds only[z] (no. species$\cdot m^{-2}$) Year 1	Year 2	Mean
0	0	Pre	1.38	4.00	2.69
		Post	2.63	5.00	3.81
		Inoc	1.50	4.00	2.75
		Unt	2.13	4.13	3.13
	1.8	Pre	1.75	3.25	2.50
		Post	2.88	4.13	3.50
		Inoc	1.75	3.75	2.75
		Unt	2.38	3.13	2.75
	3.6	Pre	0.88	2.50	1.69
		Post	2.13	3.13	2.63
		Inoc	2.38	2.88	2.63
		Unt	2.25	3.38	2.81
	5.4	Pre	1.88	2.88	2.38
		Post	2.88	4.25	3.56
		Inoc	1.88	3.25	2.56
		Unt	2.00	3.00	2.50
28	0	Pre	3.25	5.00	4.13
		Post	3.88	5.75	4.81
		Inoc	3.00	5.75	4.38
		Unt	3.50	5.13	4.31
	1.8	Pre	2.63	4.63	3.63
		Post	3.13	4.25	3.69
		Inoc	3.88	4.50	4.19
		Unt	3.75	5.25	4.50
	3.6	Pre	2.63	4.25	3.44
		Post	2.75	4.88	3.81
		Inoc	2.38	4.38	3.38
		Unt	3.00	4.50	3.75
	5.4	Pre	2.50	3.88	3.19
		Post	2.75	3.50	3.13
		Inoc	3.38	5.63	4.50
		Unt	4.00	4.75	4.38

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Table 4.4. continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Species richness - Weeds only (no. species$\cdot m^{-2}$) Year 1	Year 2	Mean
56	0	Pre	3.00	5.88	4.44
		Post	3.88	5.75	4.81
		Inoc	3.13	5.75	4.44
		Unt	2.63	4.50	3.56
	1.8	Pre	3.00	5.13	4.06
		Post	2.50	4.25	3.38
		Inoc	2.63	4.88	3.75
		Unt	3.63	6.00	4.81
	3.6	Pre	1.88	3.50	2.69
		Post	3.38	4.13	3.75
		Inoc	3.25	4.00	3.63
		Unt	3.38	4.13	3.75
	5.4	Pre	3.63	4.50	4.06
		Post	3.75	4.63	4.19
		Inoc	4.38	4.88	4.63
		Unt	3.63	4.88	4.25
112	0	Pre	2.00	4.50	3.25
		Post	2.88	5.13	4.00
		Inoc	2.25	4.63	3.44
		Unt	3.25	5.88	4.56
	1.8	Pre	1.63	4.25	2.94
		Post	1.88	5.00	3.44
		Inoc	2.50	4.25	3.38
		Unt	2.88	5.63	4.25
	3.6	Pre	1.75	3.00	2.38
		Post	2.00	3.00	2.50
		Inoc	2.13	4.13	3.13
		Unt	3.75	4.50	4.13
	5.4	Pre	2.25	3.63	2.94
		Post	1.88	3.88	2.88
		Inoc	2.50	3.88	3.19
		Unt	2.00	5.25	3.63

[z]In Year 1, no treatment effects were significant. In Year 2, ANOVA indicated nitrogen and density affected richness at P=0.031 and P=0.002, respectively.

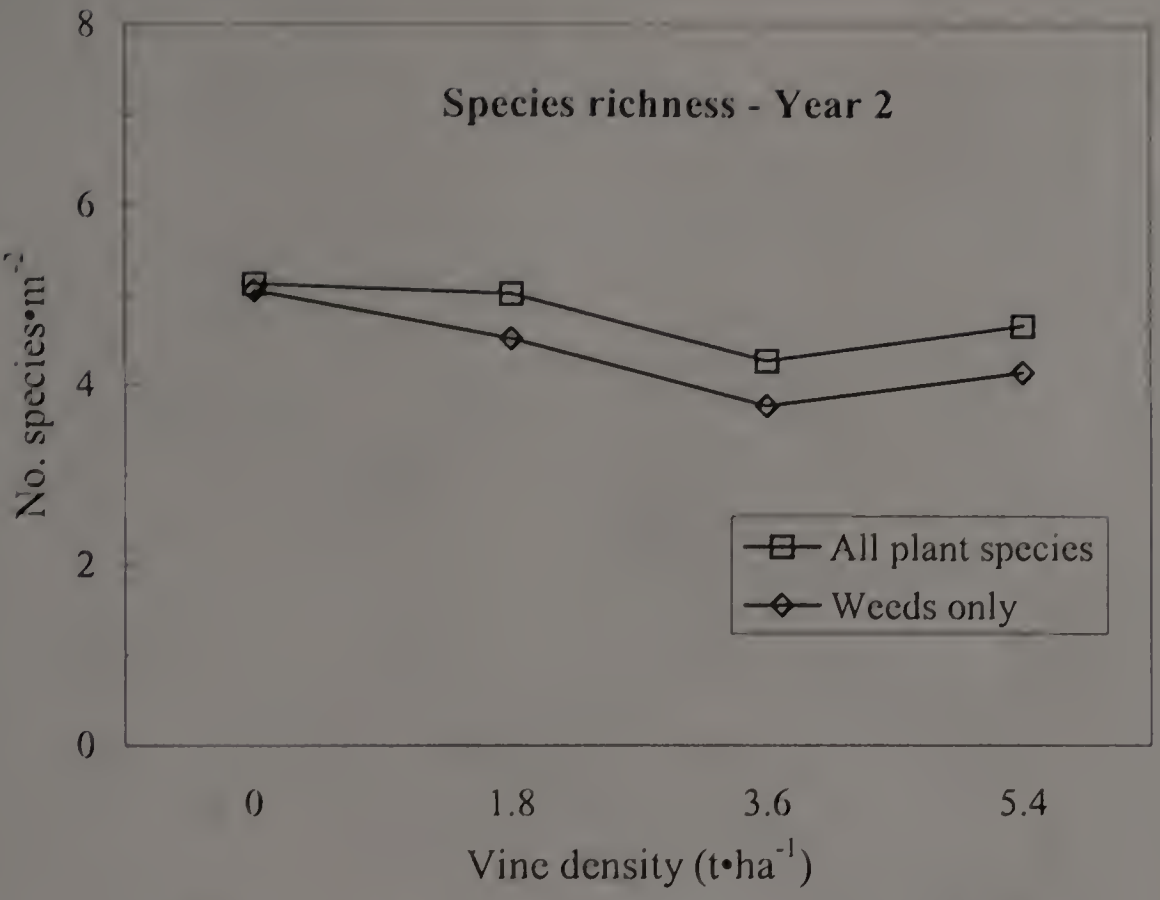

Figure 4.3. Effect of vine density on species richness in Year 2 (N=64).

Table 4.5. All plant species. Shannon's diversity index values for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Diversity (H') - All plant species		
			Year 1	Year 2	Mean
0	0	Pre	0.59	2.04	1.31
		Post	1.34	2.27	1.81
		Inoc	0.84	2.04	1.44
		Unt	1.28	2.07	1.67
	1.8	Pre	1.15	1.89	1.52
		Post	1.51	2.05	1.78
		Inoc	1.31	2.00	1.66
		Unt	1.38	1.81	1.59
	3.6	Pre	0.72	1.61	1.16
		Post	1.33	1.75	1.54
		Inoc	1.57	1.70	1.63
		Unt	1.46	1.86	1.66
	5.4	Pre	1.16	1.70	1.43
		Post	1.68	1.97	1.82
		Inoc	1.25	1.78	1.52
		Unt	1.40	1.70	1.55
28	0	Pre	1.76	2.24	2.00
		Post	1.95	2.37	2.16
		Inoc	1.63	2.30	1.96
		Unt	1.71	2.15	1.93
	1.8	Pre	1.57	2.04	1.81
		Post	1.80	2.05	1.93
		Inoc	1.94	2.13	2.03
		Unt	1.89	2.27	2.08
	3.6	Pre	1.44	1.99	1.71
		Post	1.42	2.15	1.78
		Inoc	1.54	2.09	1.81
		Unt	1.75	2.15	1.95
	5.4	Pre	1.35	1.80	1.57
		Post	1.61	1.72	1.67
		Inoc	1.78	2.26	2.02
		Unt	1.91	2.06	1.99

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Table 4.5. continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Diversity (H') -All plant species		
			Year 1	Year 2	Mean
56	0	Pre	1.54	2.35	1.94
		Post	1.96	2.30	2.13
		Inoc	1.64	2.29	1.97
		Unt	1.55	2.00	1.78
	1.8	Pre	1.67	2.17	1.92
		Post	1.69	2.03	1.86
		Inoc	1.68	2.20	1.94
		Unt	1.93	2.38	2.16
	3.6	Pre	1.21	1.80	1.51
		Post	1.65	1.96	1.81
		Inoc	1.87	1.96	1.91
		Unt	1.83	2.04	1.94
	5.4	Pre	1.92	2.02	1.97
		Post	1.88	2.01	1.95
		Inoc	2.10	2.22	2.16
		Unt	1.93	2.22	2.07
112	0	Pre	1.30	2.12	1.71
		Post	1.54	2.23	1.89
		Inoc	1.39	1.98	1.68
		Unt	1.72	2.31	2.02
	1.8	Pre	1.16	2.01	1.59
		Post	1.20	2.11	1.66
		Inoc	1.60	2.07	1.83
		Unt	1.55	2.28	1.91
	3.6	Pre	1.17	1.65	1.41
		Post	1.33	1.64	1.49
		Inoc	1.51	1.98	1.74
		Unt	1.90	2.09	1.99
	5.4	Pre	1.14	1.80	1.47
		Post	1.15	1.87	1.51
		Inoc	1.57	1.91	1.74
		Unt	1.46	2.25	1.85

[z]In Year 1, WMO affected diversity (P=0.004).

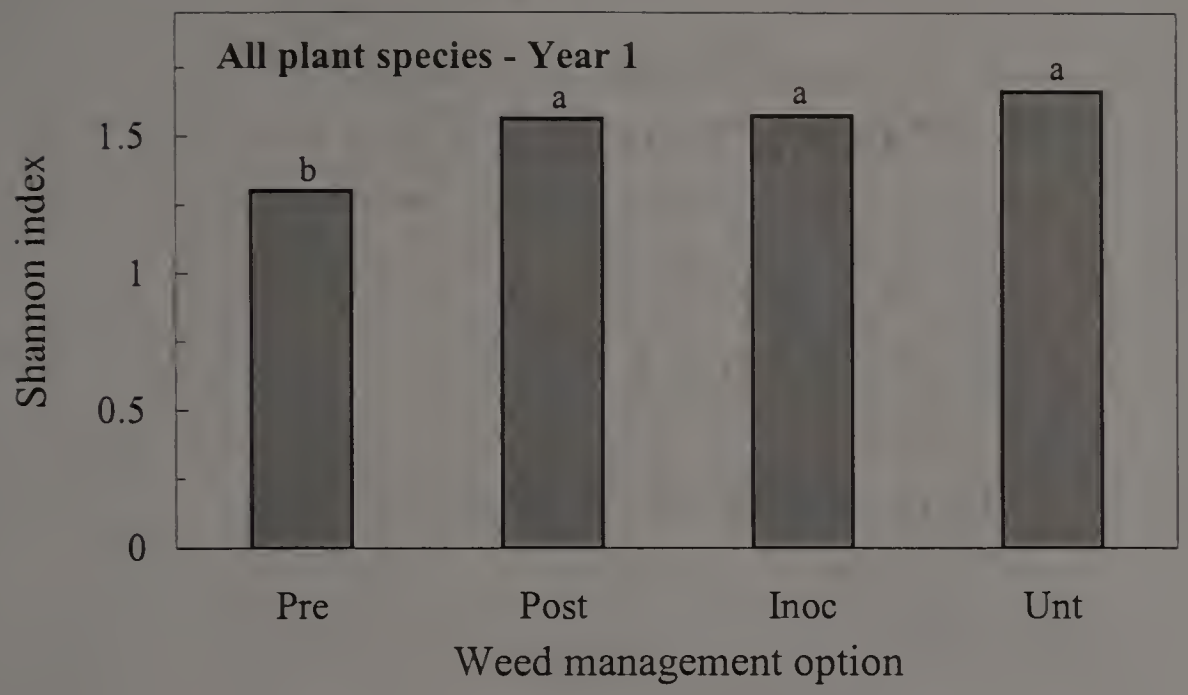

Figure 4.4. Effect of weed management option on Shannon diversity index for all plant species in Year 1 (N=64). Means with similar letters are not significantly different according to Kramer-adjusted Tukey HSD (P=0.05).

Table 4.6. Weed species only. Percentage cover from vegetation surveys for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cover - Weeds[z]		
			Year 1	Year 2	Mean
0	0	Pre	0.1	13.4	6.7
		Post	0.1	32.3	16.2
		Inoc	0.1	17.0	8.5
		Unt	0.8	26.2	13.5
	1.8	Pre	0.1	4.2	2.1
		Post	0.1	12.6	6.3
		Inoc	0.1	12.0	6.0
		Unt	0.8	6.4	3.6
	3.6	Pre	0.1	1.6	0.8
		Post	0.1	4.2	2.1
		Inoc	1.6	6.3	3.9
		Unt	0.2	10.0	5.1
	5.4	Pre	0.1	3.8	1.9
		Post	0.1	12.6	6.3
		Inoc	0.1	9.3	4.7
		Unt	0.8	6.9	3.9
28	0	Pre	4.8	40.0	22.4
		Post	8.7	45.9	27.3
		Inoc	8.7	56.1	32.4
		Unt	10.0	56.1	33.0
	1.8	Pre	1.6	22.6	12.1
		Post	5.3	21.0	13.1
		Inoc	15.6	33.3	24.4
		Unt	14.8	47.0	30.9
	3.6	Pre	1.6	17.8	9.7
		Post	1.2	26.2	13.7
		Inoc	2.0	25.2	13.6
		Unt	7.6	31.5	19.5
	5.4	Pre	0.1	10.0	5.0
		Post	2.5	8.7	5.6
		Inoc	10.6	36.2	23.4
		Unt	14.8	32.3	23.6

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Table 4.6. continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Percentage cover - Weeds		
			Year 1	Year 2	Mean
56	0	Pre	2.0	60.1	31.0
		Post	5.8	64.1	35.0
		Inoc	5.9	79.0	42.5
		Unt	3.3	50.0	26.7
	1.8	Pre	2.0	29.7	15.9
		Post	1.6	25.2	13.4
		Inoc	7.6	53.0	30.3
		Unt	26.9	64.1	45.5
	3.6	Pre	0.1	10.7	5.4
		Post	1.2	19.4	10.3
		Inoc	12.6	29.7	21.1
		Unt	12.6	33.3	23.0
	5.4	Pre	14.8	21.0	17.9
		Post	8.7	22.6	15.7
		Inoc	36.1	54.0	45.1
		Unt	25.2	51.9	38.5
112	0	Pre	0.1	38.1	19.1
		Post	0.8	62.1	31.5
		Inoc	4.8	62.1	33.4
		Unt	15.6	83.9	49.7
	1.8	Pre	0.1	25.2	12.6
		Post	0.1	41.1	20.6
		Inoc	5.8	49.0	27.4
		Unt	5.8	59.0	32.4
	3.6	Pre	0.1	7.4	3.7
		Post	0.1	14.0	7.0
		Inoc	4.8	44.8	24.8
		Unt	14.8	43.9	29.4
	5.4	Pre	0.1	14.8	7.4
		Post	0.1	20.2	10.1
		Inoc	4.3	37.1	20.7
		Unt	6.3	54.0	30.2

[z]Nitrogen and WMO interacted to affect percentage cover during the first two years of growth ($P=0.015$). In 2001, density affected percentage cover ($P<0.001$).

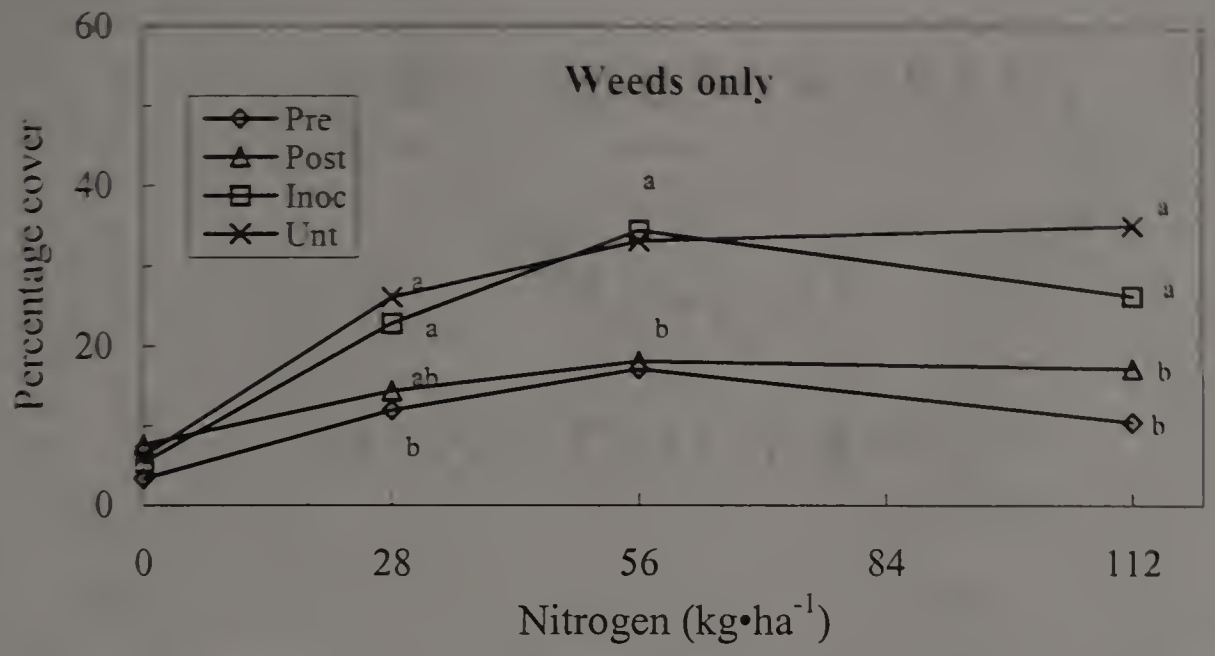

Figure 4.5. Weeds only. Interaction of nitrogen rate and WMO on percentage cover during the first two years (N=32). Signifcant differences among WMO occurred at all N rates. Means, within each N level, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

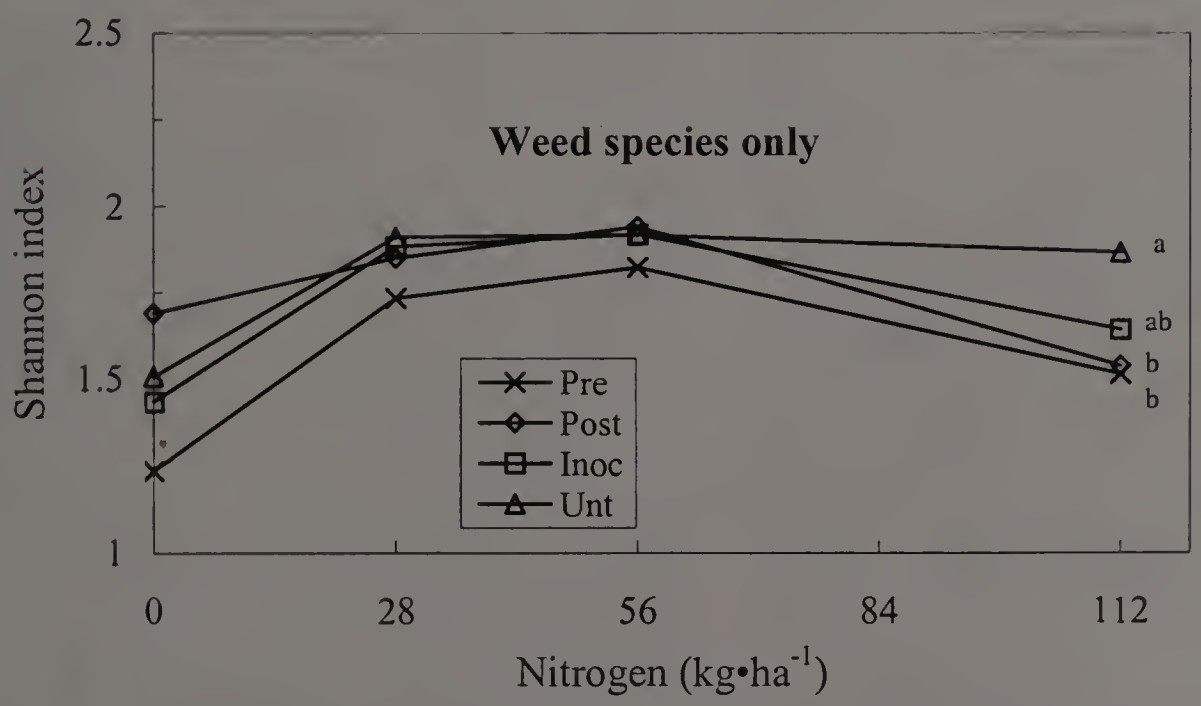

Figure 4.6. Weed species only. Interaction of nitrogen rate and weed management option on Shannon diversity index in the first two years (N=32). Significant differences among WMO occurred at high N rates. Means, within each N level, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

Table 4.7. Weed species only. Shannon's diversity index values for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Diversity (H') - Weeds only[z]		
			Year 1	Year 2	Mean
0	0	Pre	0.59	2.04	1.31
		Post	1.34	2.25	1.80
		Inoc	0.84	1.96	1.40
		Unt	1.28	2.02	1.65
	1.8	Pre	0.87	1.82	1.35
		Post	1.36	1.98	1.67
		Inoc	1.00	1.91	1.46
		Unt	1.05	1.70	1.37
	3.6	Pre	0.34	1.54	0.94
		Post	1.24	1.69	1.46
		Inoc	1.43	1.61	1.52
		Unt	1.29	1.84	1.57
	5.4	Pre	1.00	1.69	1.35
		Post	1.67	1.99	1.83
		Inoc	1.00	1.74	1.37
		Unt	1.21	1.67	1.44
28	0	Pre	1.76	2.24	2.00
		Post	1.95	2.36	2.15
		Inoc	1.63	2.30	1.96
		Unt	1.71	2.15	1.93
	1.8	Pre	1.34	2.03	1.69
		Post	1.67	2.04	1.85
		Inoc	1.77	2.03	1.90
		Unt	1.70	2.13	1.92
	3.6	Pre	1.23	2.04	1.63
		Post	1.39	2.19	1.79
		Inoc	1.36	2.05	1.71
		Unt	1.61	2.12	1.86
	5.4	Pre	1.30	1.94	1.62
		Post	1.42	1.79	1.61
		Inoc	1.60	2.33	1.97
		Unt	1.78	2.10	1.94

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Table 4.7, continued

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Diversity (H') - Weeds only		
			Year 1	Year 2	Mean
56	0	Pre	1.54	2.33	1.93
		Post	1.96	2.27	2.11
		Inoc	1.64	2.29	1.97
		Unt	1.55	2.00	1.78
	1.8	Pre	1.47	2.23	1.85
		Post	1.55	2.04	1.79
		Inoc	1.49	2.12	1.80
		Unt	1.78	2.31	2.05
	3.6	Pre	1.15	1.87	1.51
		Post	1.70	2.04	1.87
		Inoc	1.72	1.92	1.82
		Unt	1.72	1.98	1.85
	5.4	Pre	1.86	2.14	2.00
		Post	1.85	2.12	1.98
		Inoc	1.97	2.19	2.08
		Unt	1.81	2.18	1.99
112	0	Pre	1.30	2.12	1.71
		Post	1.54	2.20	1.87
		Inoc	1.39	1.98	1.68
		Unt	1.72	2.31	2.02
	1.8	Pre	1.02	2.03	1.53
		Post	0.93	2.15	1.54
		Inoc	1.39	1.95	1.67
		Unt	1.30	2.20	1.75
	3.6	Pre	0.98	1.73	1.35
		Post	1.17	1.58	1.38
		Inoc	1.30	1.89	1.60
		Unt	1.82	2.06	1.94
	5.4	Pre	1.09	1.85	1.47
		Post	0.87	1.88	1.37
		Inoc	1.42	1.83	1.62
		Unt	1.28	2.24	1.76

[z]ANOVA indicated the effect of WMO on diversity varied with nitrogen (P=0.044).

Table 4.8. Mean cover class values of cranberry growth for all treatment combinations (N=4).

Nitrogen ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed option	Cover class value[z]	
			Year 1	Year 2
0	0	Pre	0.00	0.00
		Post	0.00	0.50
		Inoc	0.00	0.75
		Unt	0.00	0.50
	1.8	Pre	4.00	4.25
		Post	3.75	4.25
		Inoc	3.25	4.25
		Unt	3.50	4.25
	3.6	Pre	4.75	5.25
		Post	4.75	5.50
		Inoc	4.50	5.75
		Unt	4.50	6.25
	5.4	Pre	5.50	6.25
		Post	4.75	6.50
		Inoc	5.00	6.25
		Unt	5.00	6.75
28	0	Pre	0.00	0.00
		Post	0.25	0.25
		Inoc	0.00	0.00
		Unt	0.00	0.00
	1.8	Pre	4.00	6.75
		Post	3.50	6.50
		Inoc	3.25	4.50
		Unt	3.00	3.75
	3.6	Pre	4.25	7.50
		Post	4.50	7.50
		Inoc	4.00	6.25
		Unt	3.75	6.25
	5.4	Pre	5.25	9.00
		Post	4.75	8.50
		Inoc	4.50	8.25
		Unt	4.75	8.00

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Table 4.8, continued

Nitrogen ($kg*ha^{-1}$)	Vine density ($r*ha^{-1}$)	Weed option	Cover class value	
			Year 1	Year 2
56	0	Pre	0.00	0.25
		Post	0.00	0.50
		Inoc	0.00	0.00
		Unt	0.00	0.00
	1.8	Pre	3.75	8.00
		Post	3.50	7.50
		Inoc	3.25	5.50
		Unt	3.50	5.00
	3.6	Pre	5.25	8.25
		Post	5.00	8.75
		Inoc	3.75	7.25
		Unt	4.75	6.50
	5.4	Pre	5.25	9.00
		Post	5.00	9.00
		Inoc	3.50	7.25
		Unt	5.00	6.75
112	0	Pre	0.00	0.00
		Post	0.00	0.50
		Inoc	0.00	0.00
		Unt	0.00	0.00
	1.8	Pre	3.75	8.00
		Post	4.00	8.25
		Inoc	3.00	4.25
		Unt	4.25	5.75
	3.6	Pre	5.25	9.00
		Post	4.75	9.00
		Inoc	4.25	7.25
		Unt	5.25	8.25
	5.4	Pre	5.75	9.00
		Post	5.00	8.75
		Inoc	5.00	8.00
		Unt	5.25	8.25

[a]In Year 1, nitrogen and density affected CCV ($P \leq 0.003$).
In Year 2, N*D, N*W, and D*W affected CCV ($P < 0.001$).

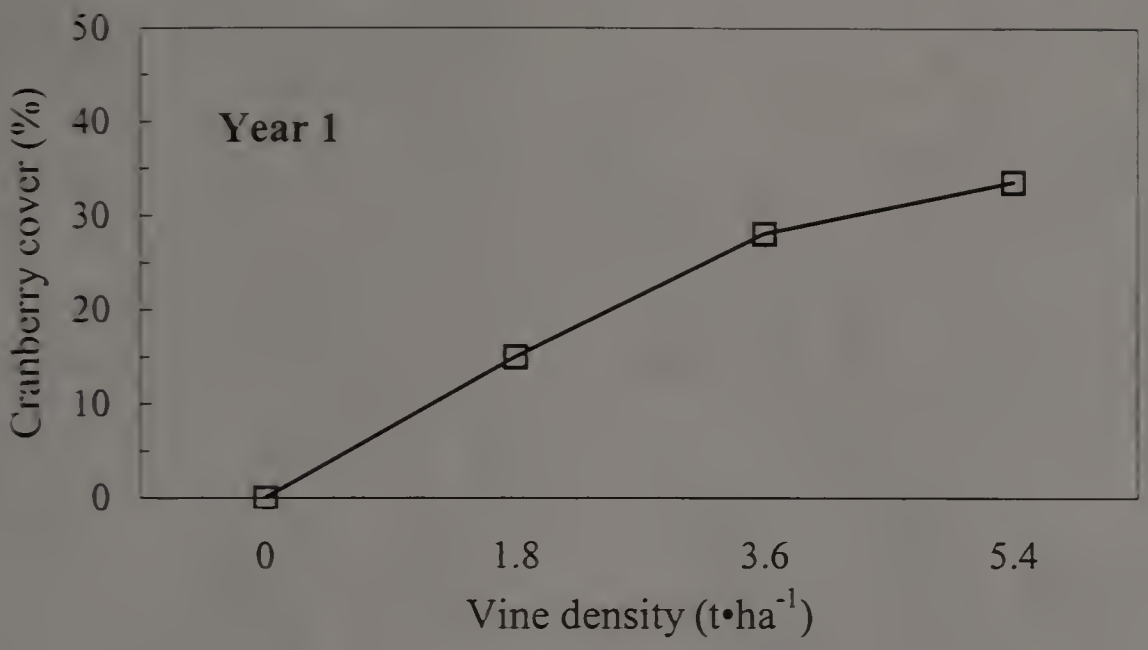


Figure 4.7. Effect of vine density on percentage cranberry cover in Year 1 (N=64).

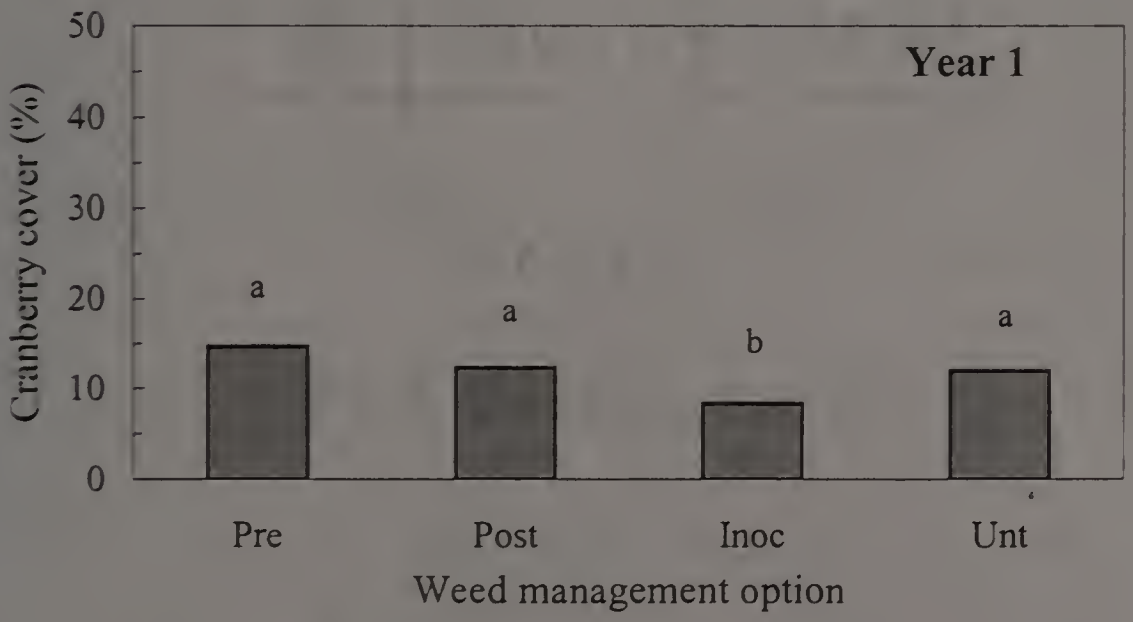


Figure 4.8. Effect of weed management option on percentage cranberry cover in Year 1 (N=64). Means with similar letters are not significantly different according to Kramer-adjusted Tukey's HSD (P=0.05).

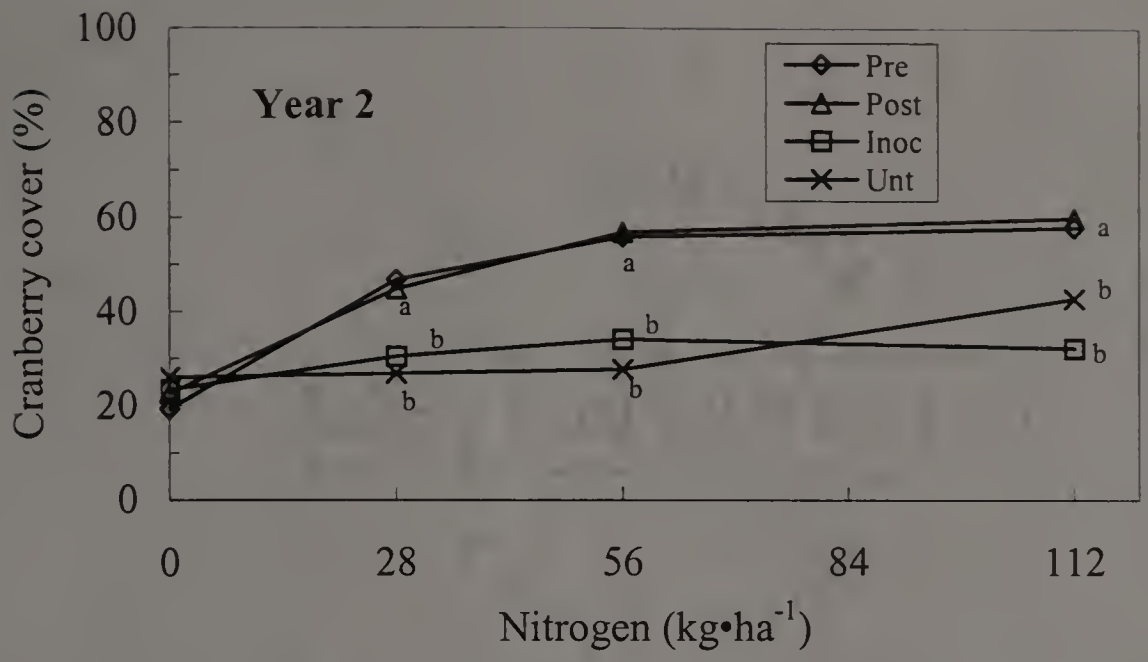


Figure 4.9. Interaction of nitrogen rate and weed management option on percentage cranberry cover in Year 2 (N=16). Significant differences occurred among WMO for low, medium, and high N rates. Means, within each N level, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

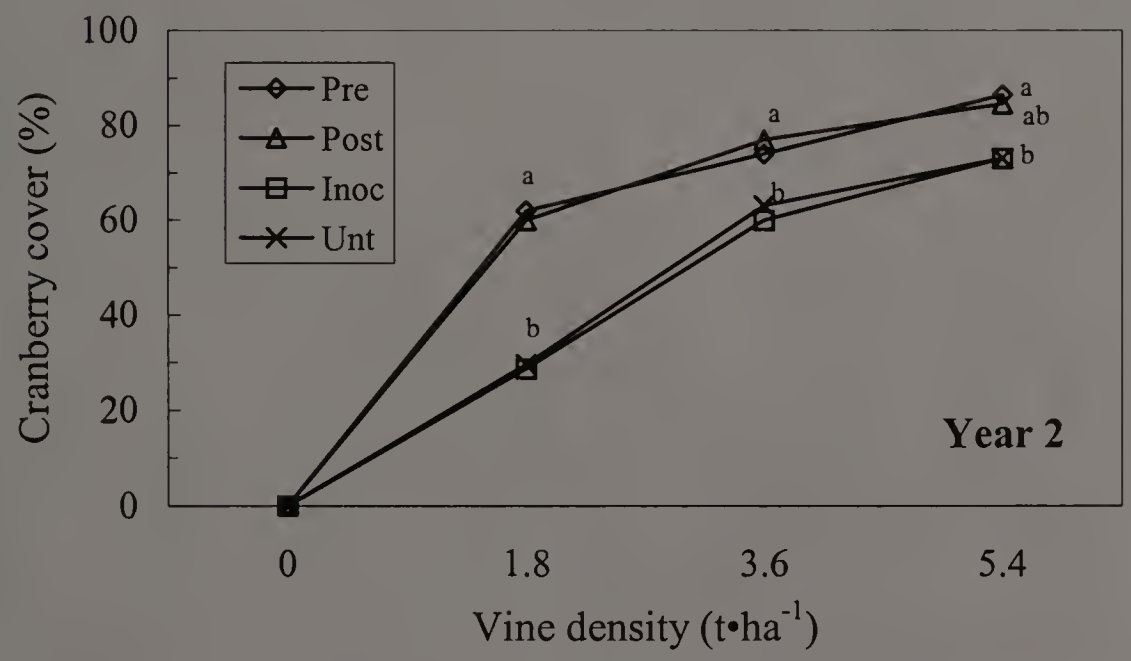


Figure 4.10. Interaction of vine density and weed management option on percentage cranberry cover in Year 2 (N=16). Significant differences occurred among WMO for low, medium, and high densities. Means, within each density, with similar letters are not significantly different by t-test using Bonferroni-adjusted p-value (P=0.008).

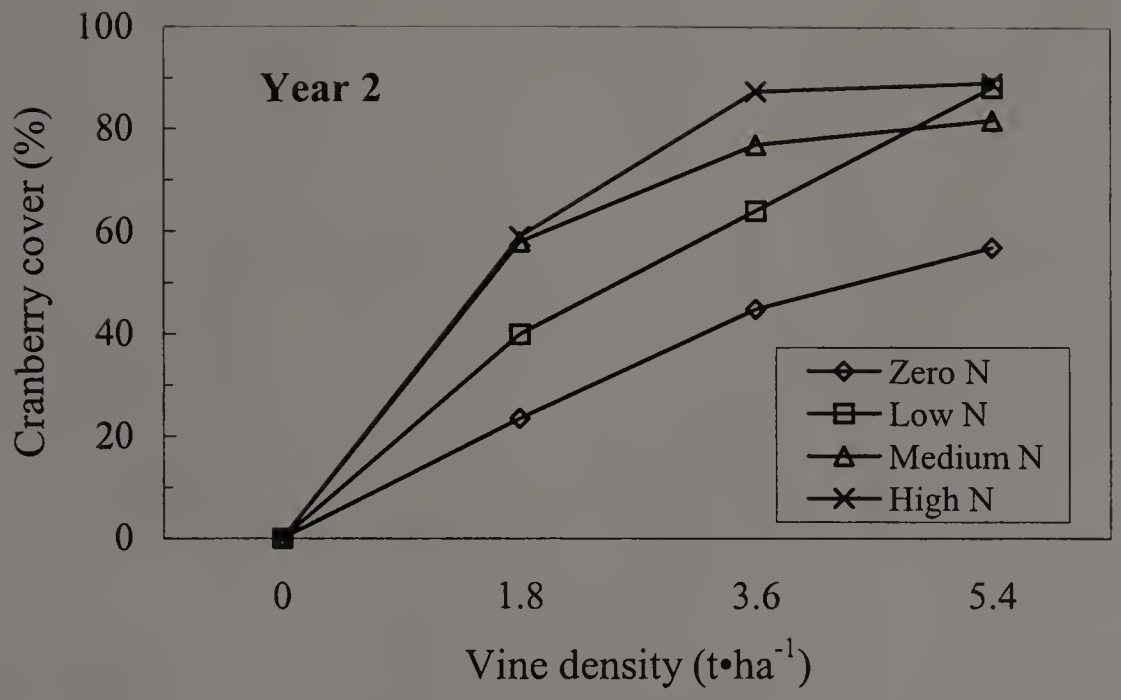


Figure 4.11. Interaction of nitrogen rate and vine density on percentage cranberry cover in Year 2 (N=16). Significant differences occurred among vine density for all N rates.

Table 4.9. All plant species. Percentage frequency and percentage cover by nitrogen rate.

Zero nitrogen	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	75.0	25.2	*V. macrocarpon*	82.8	35.0
Digitaria sanguinalis	65.6	3.7	*C. dentatus*	82.8	1.5
Cyperus dentatus	53.1	0.3	*M. capallaris*	76.6	4.3
Agrostis hyemalis	37.5	0.5	*E. tenuifolia*	73.4	0.8
Euthamia tenuifolia	31.3	0.8	*Hypericum sp.*	64.1	0.5
Bidens frondosa	31.2	0.3	*J. canadensis*	42.2	1.3
Linaria canadensis	28.1	0.3	*V. lanceolata*	42.2	0.3
Juncus canadensis	25.0	0.5	*H. gentianoides*	32.8	0.3
Hypericum gentianoides	17.2	0.7	*D. sanguinalis*	3.1	1.2

Low nitrogen	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	76.6	19.8	*Cyperus dentatus*	89.1	2.9
D. sanguinalis	71.9	8.4	*M. capallaris*	82.8	9.1
Cyperus dentatus	59.4	0.4	*V. macrocarpon*	76.6	63.7
Linaria canadensis	56.3	0.6	*E. tenuifolia*	75.0	1.7
Agrostis hyemalis	48.4	1.2	*Hypericum sp.*	70.3	1.2
Bidens frondosa	43.8	0.3	*Viola lanceolata*	57.8	0.3
Ambrosia artemisiifolia	40.6	0.9	*Ambrosia artemisiifolia*	51.6	0.3
H. gentianoides	31.3	0.3	*H. gentianoides*	46.9	1.3
Hypericum sp.	31.3	1.1	*J. canadensis*	43.8	0.8
E. tenuifolia	28.1	0.7	*Panicum sp.*	42.2	4.3

Medium nitrogen	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
V. macrocarpon	76.6	22.4	*Cyperus dentatus*	90.6	6.3
D. sanguinalis	71.9	9.3	*E. tenuifolia*	85.9	5.5
Cyperus dentatus	67.2	0.6	*M. capallaris*	82.8	25.7
Agrostis hyemalis	54.7	2.6	*V. macrocarpon*	79.7	67.8
Linaria canadensis	50.0	0.5	*Hypericum sp.*	56.3	1.4
Bidens frondosa	48.4	0.5	*Viola lanceolata*	56.3	0.5
E. tenuifolia	43.8	0.3	*Panicum sp.*	51.6	3.2
Spergularia rubrum	31.3	1.2	*Juncus canadensis*	45.3	0.7
Ambrosia artemisiifolia	28.1	1.0	*Ambrosia artemisiifolia*	43.8	0.5
D. ischaemum	6.2	7.7	*D. sanguinalis*	28.1	4.4

High nitrogen	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
V. macrocarpon	75.0	28.0	*Cyperus dentatus*	95.3	8.1
Cyperus dentatus	68.8	0.5	*M. capallaris*	81.3	36.3
D. sanguinalis	67.2	9.2	*E. tenuifolia*	78.1	4.7
Agrostis hyemalis	43.8	1.1	*V. macrocarpon*	76.6	78.6
E. tenuifolia	35.9	0.6	*Linaria canadensis*	62.5	0.3
Bidens frondosa	32.8	0.3	*Ambrosia artemisiifolia*	56.3	1.9
Linaria canadensis	31.3	0.7	*Panicum sp.*	54.7	6.9
Ambrosia artemisiifolia	20.3	0.7	*D. sanguinalis*	40.6	6.3

Table 4.10. All plant species. Percentage frequency and percentage cover by vine density.

No vines	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Cyperus dentatus	67.2	0.3	*Cyperus dentatus*	93.8	4.1
Digitaria sanguinalis	67.2	8.1	*Muhlenbergia capallaris*	81.3	34.1
Agrostis hyemalis	46.9	0.8	*Viola lanceolata*	81.3	0.8
Linaria canadensis	37.5	0.5	*Euthamia tenuifolia*	76.6	5.7
Euthamia tenuifolia	31.3	0.5	*Hypericum sp.*	75.0	1.8
Juncus canadensis	31.3	0.4	*Ambrosia artemisiifolia*	73.4	1.2
Hypericum sp.	28.1	1.0	*Panicum sp.*	56.3	4.9
Hypericum gentianoides	21.9	1.0	*Hypericum gentianoides*	42.2	2.3
Ambrosia artemisiifolia	18.8	0.7	*Juncus canadensis*	35.9	1.2
Mollugo verticillata	18.8	1.8	*Digitaria sanguinalis*	23.4	4.9

Low density	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	100.0	15.9	*Vaccinium macrocarpon*	100.0	44.9
Digitaria sanguinalis	73.4	7.2	*Cyperus dentatus*	85.9	20.7
Cyperus dentatus	51.6	0.4	*Muhlenbergia capallaris*	85.9	14.6
Linaria canadensis	45.3	0.9	*Euthamia tenuifolia*	76.6	2.3
Agrostis hyemalis	37.5	1.5	*Hypericum sp.*	57.8	0.9
Bidens frondosa	35.9	0.3	*Linaria canadensis*	46.9	0.3
Ambrosia artemisiifolia	32.8	1.2	*Panicum sp.*	43.8	4.7
Euthamia tenuifolia	28.1	0.7	*Aster sp.*	28.1	10.3
Hypericum gentianoides	26.6	0.5	*Digitaria sanguinalis*	25.0	9.4
Hypericum sp.	25.0	0.8	*Bidens frondosa*	6.3	7.3

Medium density	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	100.0	27.2	*Vaccinium macrocarpon*	100.0	70.0
Digitaria sanguinalis	68.8	5.7	*Cyperus dentatus*	92.2	5.6
Cyperus dentatus	64.1	0.4	*Euthamia tenuifolia*	82.8	2.1
Agrostis hyemalis	50.0	1.7	*Muhlenbergia capallaris*	78.1	12.6
Euthamia tenuifolia	43.8	0.4	*Hypericum sp.*	46.9	0.4
Bidens frondosa	39.1	0.4	*Panicum sp.*	42.2	2.7
Linaria canadensis	39.1	7.8	*Juncus canadensis*	40.6	0.7
Ambrosia artemisiifolia	21.8	0.4	*Linaria canadensis*	32.8	0.3
Spergularia rubrum	18.8	1.8	*Viola lanceolata*	32.8	0.4
			Digitaria sanguinalis	17.2	3.4

High density	Year 1		Year 2		
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	100.0	33.1	*Vaccinium macrocarpon*	100.0	80.9
Digitaria sanguinalis	67.2	9.4	*Cyperus dentatus*	85.9	4.4
Cyperus dentatus	65.6	0.5	*Muhlenbergia capallaris*	78.1	10.2
Bidens frondosa	54.7	0.5	*Euthamia tenuifolia*	76.6	2.0
Agrostis hyemalis	50.0	1.4	*Hypericum sp.*	59.4	0.7
Linaria canadensis	42.2	0.6	*Aster sp.*	42.2	0.8
Euthamia tenuifolia	35.9	0.6	*Cyperus strigosus*	40.6	1.6
Mollugo verticillata	9.4	3.7	*Panicum* sp.	35.9	2.5
D. ischaemum	9.4	2.7	*Digitaria sanguinalis*	29.7	2.3

Table 4.11. All plant species. Percentage frequency and percentage cover by WMO.

Preemergence	Year 1			Year 2	
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Digitaria sanguinalis	75.0	0.6	*Cyperus dentatus*	82.8	0.9
Vaccinium macrocarpon	75.0	29.6	*Euthamia tenuifolia*	79.7	4.2
Hypericum sp.	39.1	0.6	*Vaccinium macrocarpon*	76.6	73.8
Euthamia tenuifolia	35.9	0.3	*Hypericum sp.*	73.4	1.3
Bidens frondosa	34.4	0.3	*Hypericum gentianoides*	54.7	1.5
Molluga verticillata	31.3	2.8	*Linaria canadensis*	54.7	0.4
Cyperus dentatus	28.1	0.9	*Muhlenbergia capallaris*	54.7	1.6
Ambrosia artemisiifolia	26.6	1.0	*Viola lanceolata*	51.6	0.4
Hypericum gentianoides	21.9	0.4	*Salix sp.*	46.9	0.3
Polygonum pensylvanicum	7.8	2.0	*Ambrosia artemisiifolia*	45.3	0.4

Postemergence	Year 1			Year 2	
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Vaccinium macrocarpon	76.6	24.1	*Cyperus dentatus*	90.6	4.2
Cyperus dentatus	75.0	0.3	*Vaccinium macrocarpon*	82.8	66.2
Bidens frondosa	50.0	0.4	*Muhlenbergia capallaris*	78.1	8.6
Linaria canadensis	48.4	0.7	*Euthamia tenuifolia*	68.8	1.7
Hypericum sp.	39.1	0.7	*Viola lanceolata*	64.1	0.5
Juncus canadensis	34.4	0.5	*Hypericum sp.*	62.5	1.3
Euthamia tenuifolia	29.7	6.9	*Juncus canadensis*	60.9	1.0
Hypericum gentianoides	29.7	0.6	*Ambrosia artemisiifolia*	45.3	0.6
Spergularia rubrum	23.4	1.2	*Hypericum gentianoides*	45.3	0.5
Ambrosia artemisiifolia	23.4	1.0	*Linaria canadensis*	35.9	0.3

Inoculated	Year 1			Year 2	
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Digitaria sanguinalis	98.4	13.4	*Cyperus dentatus*	93.8	9.1
Cyperus dentatus	81.3	0.8	*Euthamia tenuifolia*	92.2	3.3
Vaccinium macrocarpon	75.0	18.2	*Muhlenbergia capallaris*	92.2	29.5
Agrostis hyemalis	68.8	1.9	*Vaccinium macrocarpon*	78.1	51.2
Linaria canadensis	50.0	0.4	*Panicum sp.*	59.4	5.0
Bidens frondosa	39.1	0.4	*Hypericum sp.*	51.6	0.5
Euthamia tenuifolia	37.5	0.8	*Juncus canadensis*	48.4	0.6
D. ischaemum	4.7	4.8	*Cyperus strigosus*	46.9	0.9
Viola lanceolata	3.1	3.7	*Digitaria sanguinalis*	23.4	5.4

Untreated	Year 1			Year 2	
Frequent species	%Frequency	%Cover	Frequent species	%Frequency	%Cover
Digitaria sanguinalis	96.9	11.7	*Muhlenbergia capallaris*	98.4	27.9
Agrostis hyemalis	78.1	1.9	*Cyperus dentatus*	90.6	5.2
Vaccinium macrocarpon	76.6	23.5	*Vaccinium macrocarpon*	78.1	52.2
Cyperus dentatus	64.1	0.6	*Euthamia tenuifolia*	71.9	2.3
Linaria canadensis	50.0	1.0	*Panicum sp.*	68.8	6.4
Euthamia tenuifolia	35.9	0.7	*Hypericum sp.*	51.6	0.7
Bidens frondosa	32.8	0.4	*Ambrosia artemisiifolia*	46.9	1.0
Ambrosia artemisiifolia	29.7	0.7	*Cyperus strigosus*	43.8	1.4
Spergularia rubrum	23.4	1.2	*Digitaria sanguinalis*	34.4	4.0
D. ischaemum	10.9	0.8	*Aster sp.*	28.1	1.8

Table 4.12. Relative abundance (RA) of plant species by nitrogen rate.
Species occuring at least once with RA >5 are listed.

All plant species

Zero nitrogen

	RA[z]	
Dominant species	Year 1	Year 2
Agrostis hyemalis	6.8	nd
Cyperus dentatus	8.3	10.2
Digitaria sanguinalis	17.1	0.4
Euthamia tenuifolia	3.7	8.2
Hypericum sp.	1.8	6.5
Muhlenbergia capallaris	nd	11.8
Vaccinium macrocarpon	34.6	24.9
Total number of species	28	33

Low nitrogen

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	6.9	nd
Ambrosia artemisiifolia	5.5	3.3
C. dentatus	6.7	8.5
D. sanguinalis	15.8	2.3
E. tenuifolia	2.3	6.4
Hypericum sp.	2.3	5.6
Linaria canadensis	7.2	2.8
M. capallaris	nd	10.5
V. macrocarpon	22.1	20.8
Total number species	33	40

Medium nitrogen

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	8.1	0.2
B. frondosa	5.3	0.2
C. dentatus	7.6	9.4
D. sanguinalis	14.6	2.7
E. tenuifolia	4.1	8.6
L. canadensis	5.6	2.6
M. capallaris	nd	13.6
V. macrocarpon	20.8	20.5
Total number of species	36	39

High nitrogen

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	7.0	0.5
C. dentatus	9.6	10.6
D. sanguinalis	17.3	4.2
M. capallaris	nd	15.3
Panicum sp.	0.3	5.8
V. macrocarpon	28.2	21.5
Total number species	33	33

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each nitrogen rate.

Table 4.13. Relative abundance (RA) of plant species by vine density.
Species occuring at least once with RA >5 are listed.

All plant species

Zero vines

	RA[z]	
Dominant species	Year 1	Year 2
Agrostis hyemalis	9.4	nd
Ambrosia artemisiifolia	3.7	6.2
Cyperus dentatus	11.6	10.1
Digitaria sanguinalis	22.0	2.6
Euthamia tenuifolia	4.4	8.9
Hypericum sp.	3.2	6.8
Linaria canadensis	7.0	3.4
Muhlenbergia capallaris	nd	17.1
Panicum sp.	nd	6.3
Viola lanceolata	1.7	6.4
Total number of species	33	37

Low density

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	5.9	0.2
C. dentatus	6.5	8.7
D. sanguinalis	16.5	3.2
E. tenuifolia	2.5	7.1
Linaria canadensis	6.5	2.7
M. capallaris	nd	12.8
V. macrocarpon	27.1	23.1
Total number species	32	38

Medium density

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	8.1	0.1
C. dentatus	8.2	10.9
D. sanguinalis	14.5	1.8
E. tenuifolia	4.5	7.9
M. capallaris	nd	11.6
V. macrocarpon	34.9	30.7
Total number of species	35	38

High density

	RA	
Dominant species	Year 1	Year 2
A. hyemalis	6.6	0.5
Bidens frondosa	6.1	0.1
C. dentatus	7.3	8.8
D. sanguinalis	13.7	2.6
E. tenuifolia	2.8	6.7
M. capallaris	nd	10.1
V. macrocarpon	31.7	31.0
Total number species	34	39

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each vine density.

Table 4.14. Relative abundance (RA) of plant species by WMO.
Species occuring at least once with RA >5 are listed.

All plant species

Preemergence

Dominant species	RA Year 1	RA Year 2
Cyperus dentatus	2.6	7.5
Digitaria sanguinalis	10.9	4.4
Euthamia tenuifolia	4.6	9.7
Hypericum gentianoides	2.4	5.4
Hypericum sp.	3.8	7.0
Molluga verticillata	6.0	nd
Muhlenbergia capallaris	nd	5.5
Vaccinium macrocarpon	29.1	26.8
Total number of species	32	36

Postemergence

Dominant species	RA Year 1	RA Year 2
B. frondosa	7.1	0.2
C. dentatus	10.2	10.0
E. tenuifolia	3.1	6.3
Hypericum sp.	3.9	5.4
J. canadensis	3.8	5.1
L. canadensis	7.6	2.3
M. capallaris	nd	10.4
V. macrocarpon	28.7	24.6
Total number species	32	38

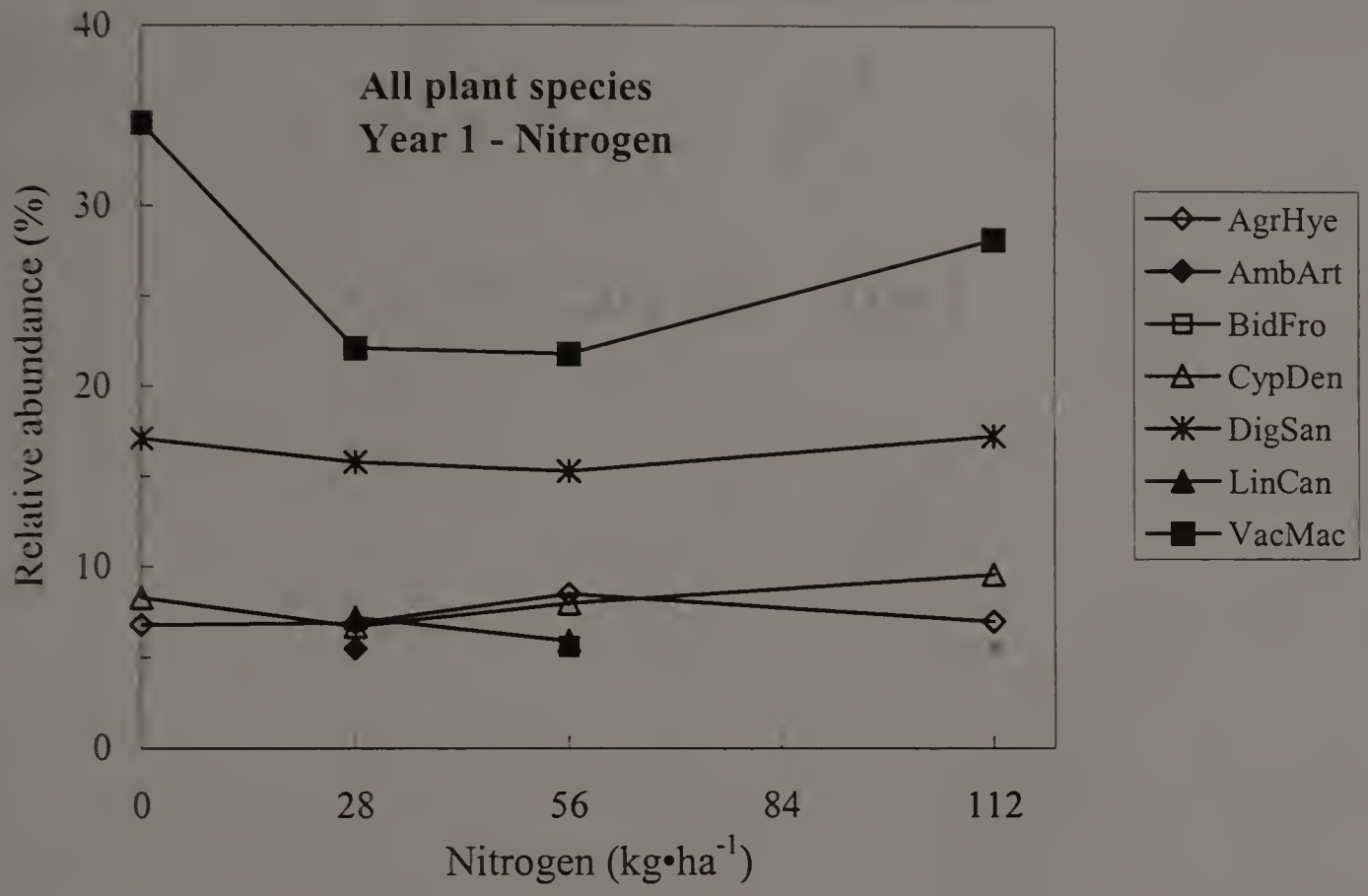
Inoculated

Dominant species	RA Year 1	RA Year 2
Agrostis hyemalis	11.0	0.3
Cyperus dentatus	11.1	11.7
Digitaria sanguinalis	25.6	2.5
Linaria canadensis	6.0	1.7
Muhlenbergia capallaris	nd	17.2
Panicum sp.	0.1	6.3
Vaccinium macrocarpon	21.6	18.7
Total number of species	29	38

Untreated

Dominant species	RA Year 1	RA Year 2
A. hyemalis	11.1	0.4
C. dentatus	7.4	9.4
D. sanguinalis	21.4	3.4
E. tenuifolia	2.7	6.2
L. canadensis	6.3	2.9
M. capallaris	nd	17.4
Panicum sp.	0.2	7.5
V. macrocarpon	21.6	18.2
Total number species	36	39

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each WMO.



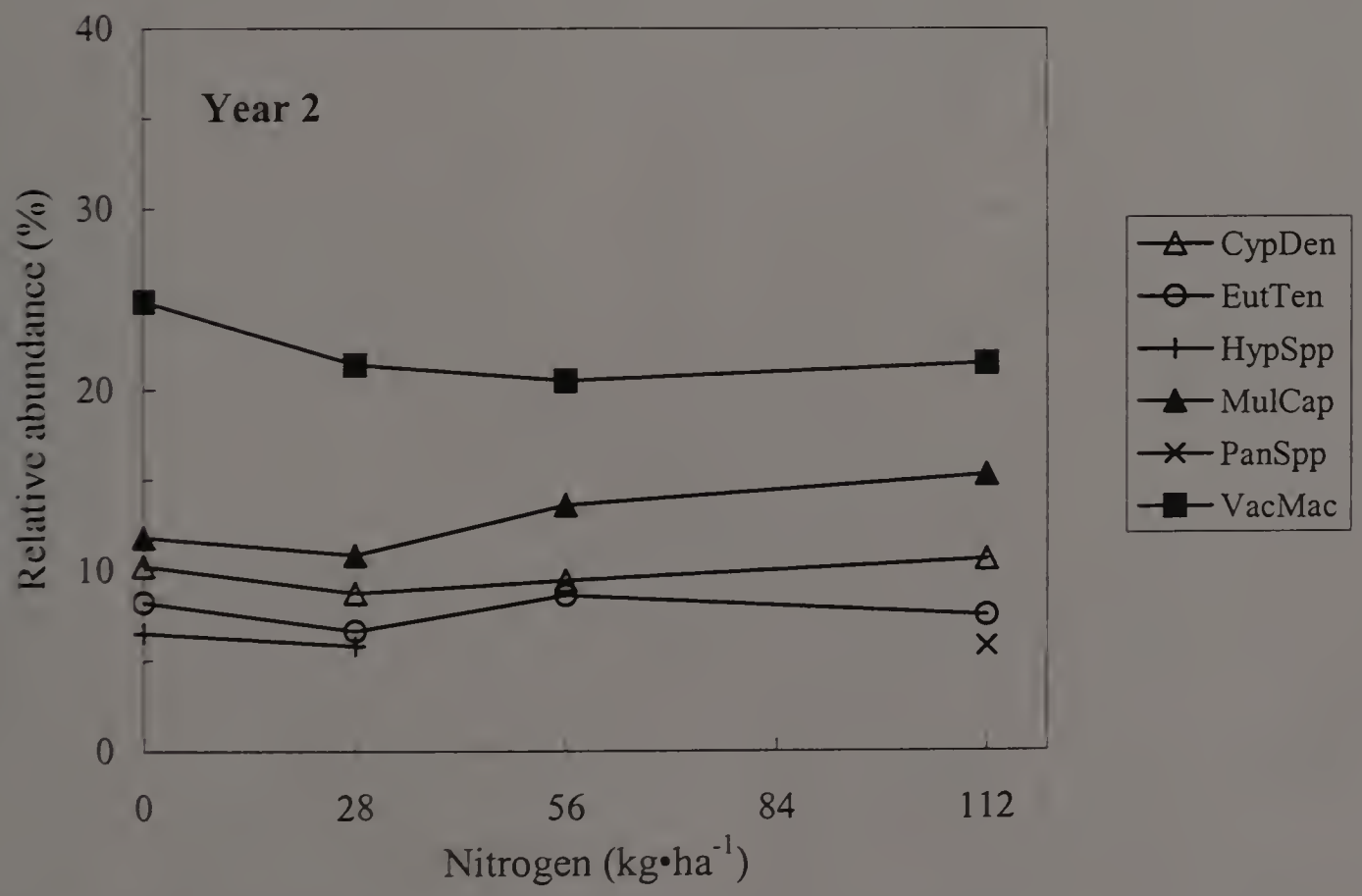
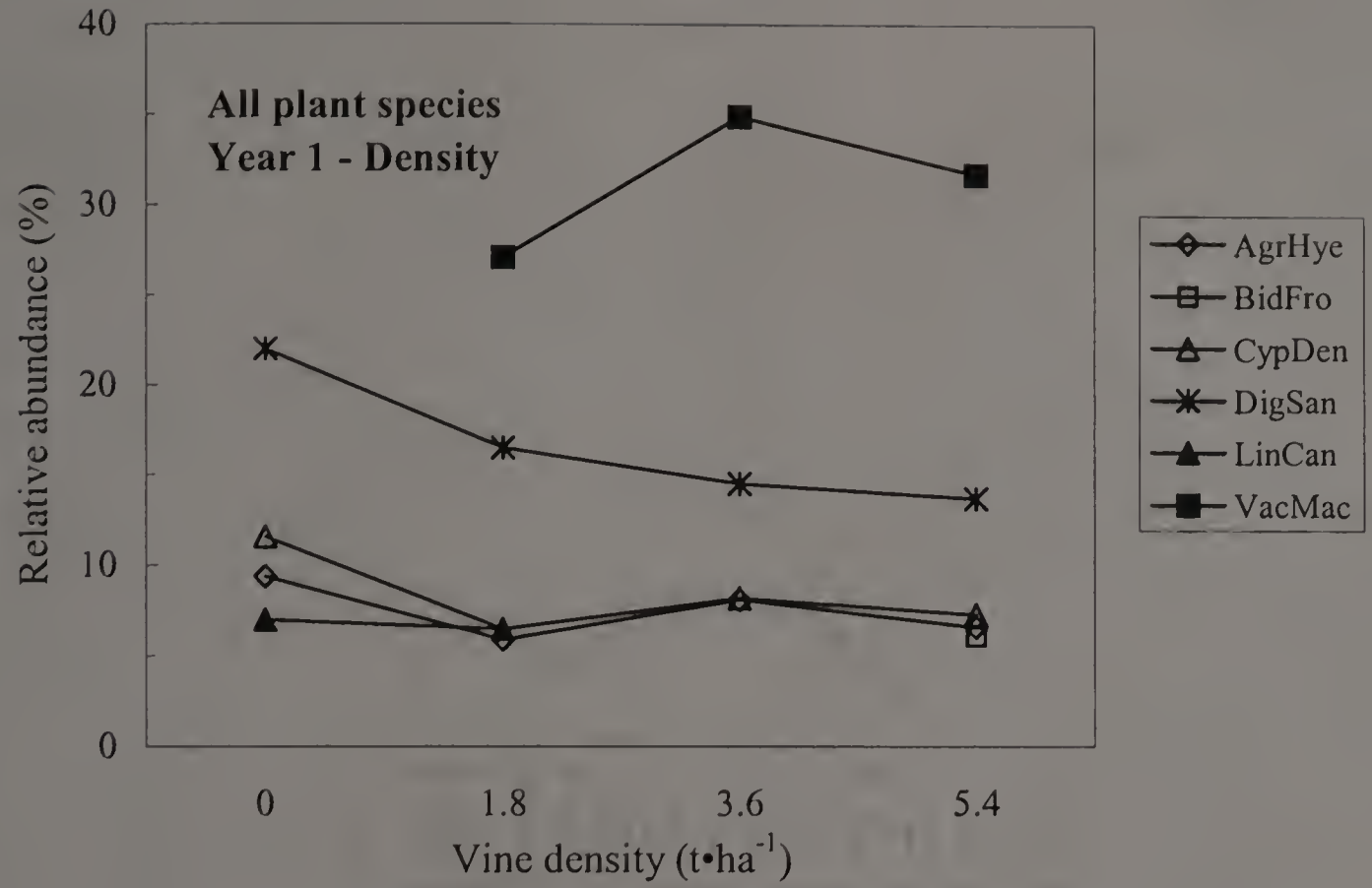


Figure 4.12. Relative abundance (min. = 5%) of dominant plant species for all plant species treated with various rates of nitrogen (N=64).



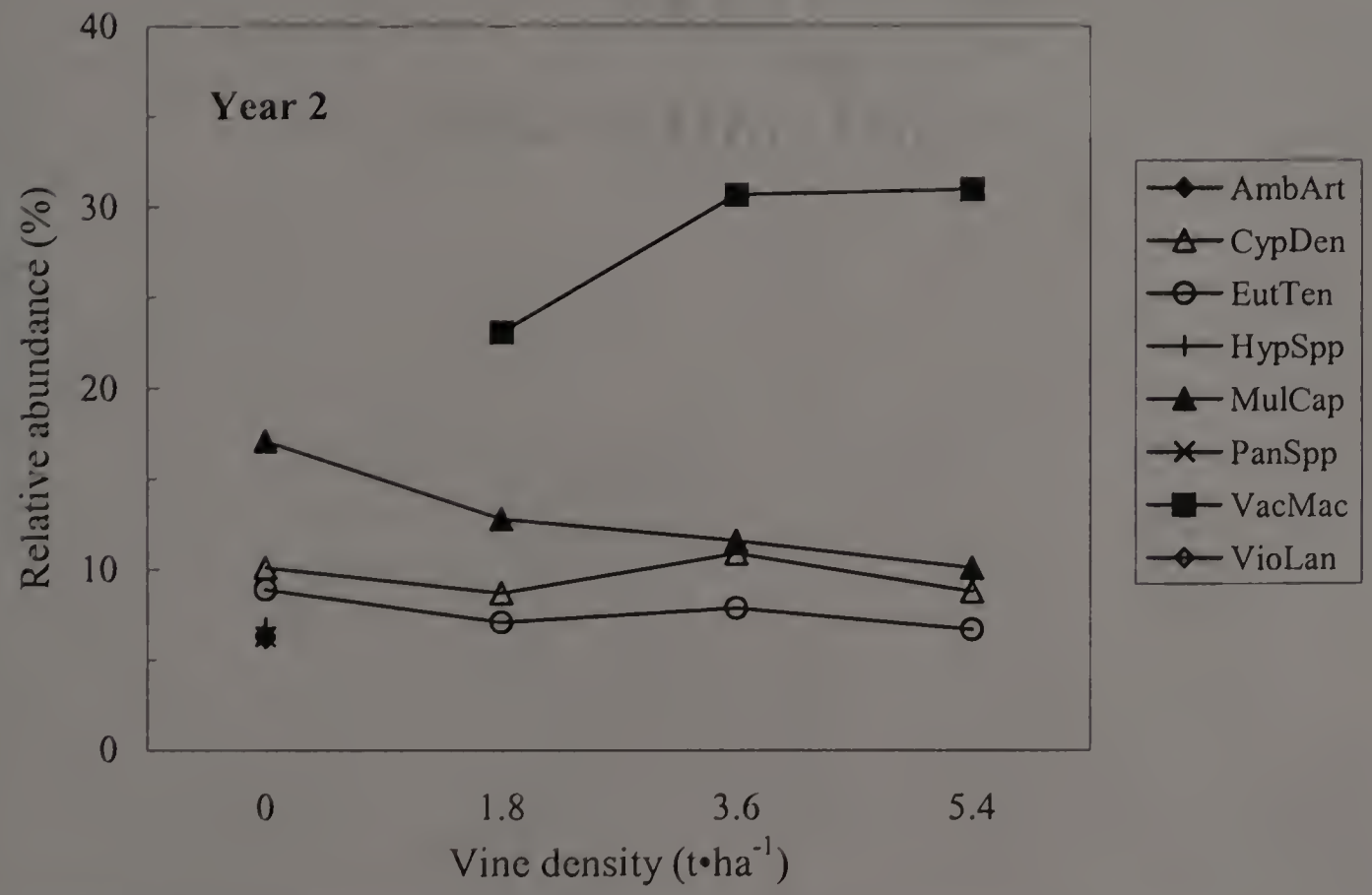
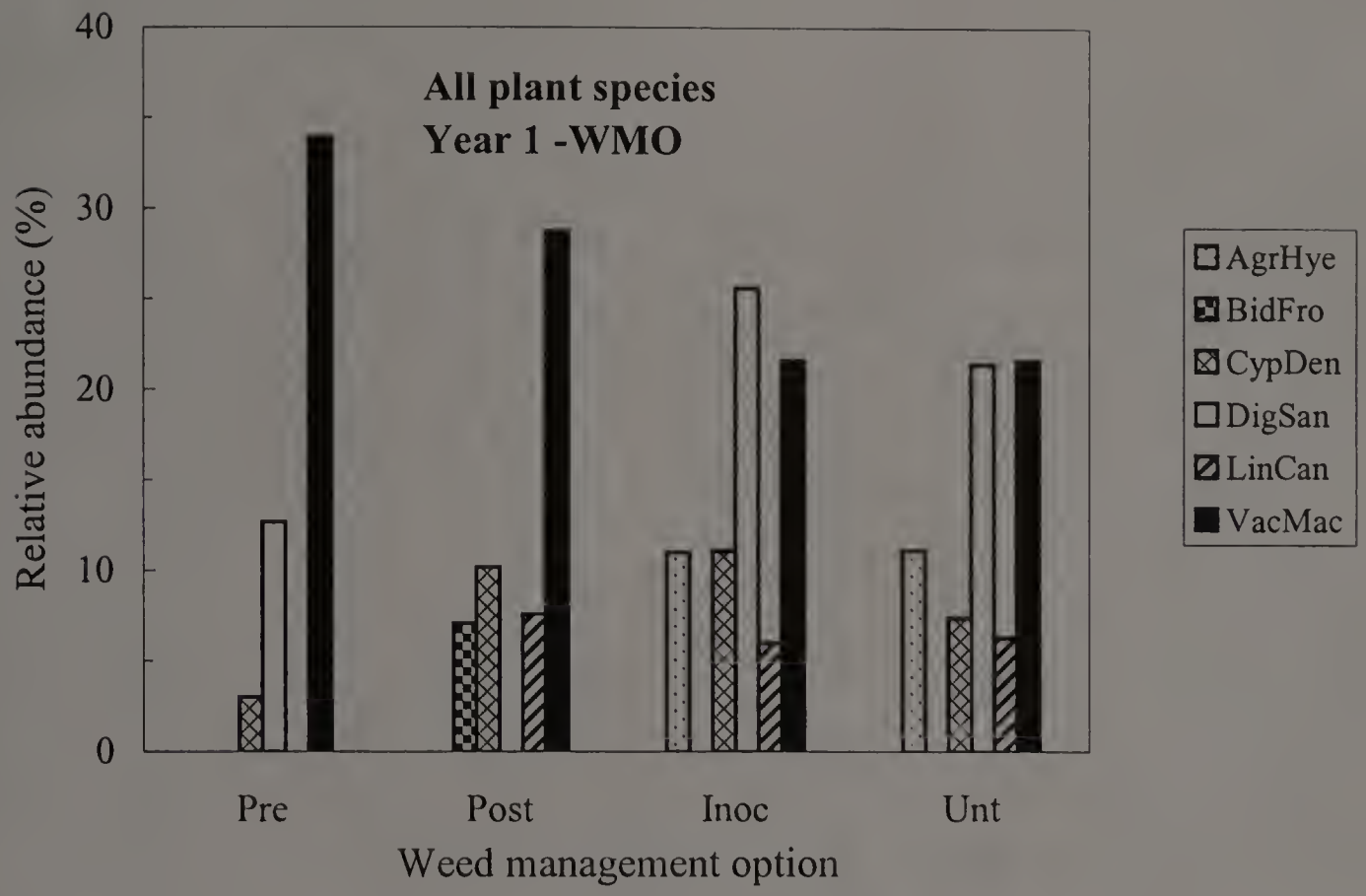


Figure 4.13. Relative abundance (min. = 5%) of dominant species for all plant species in various cranberry vine densities (N=64).



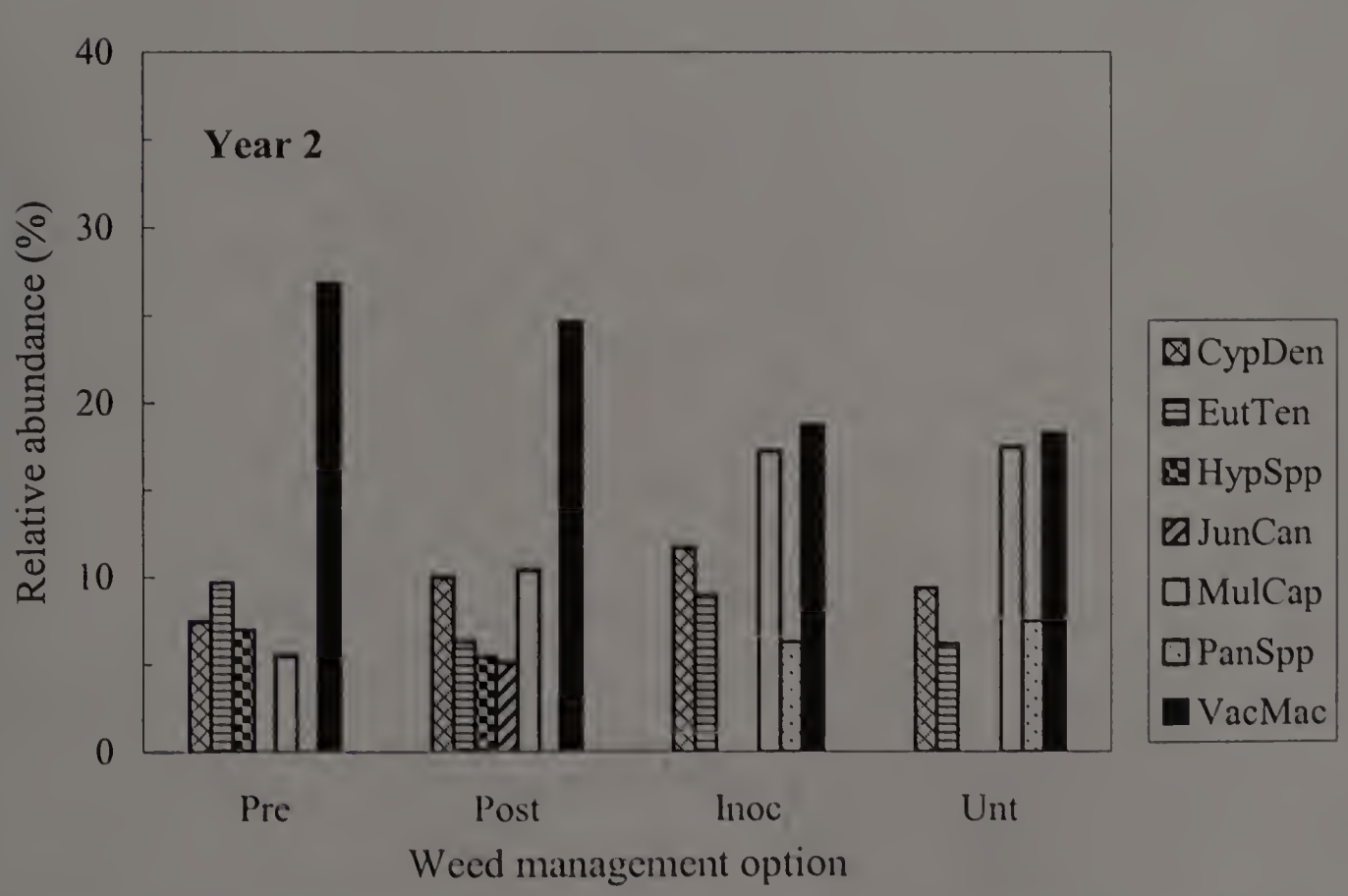


Figure 4.14. Relative abundance (min. = 5%) of dominant plant species for all plant species managed with various weed management options (N=64).

Table 4.15. Relative abundance (RA) of weed species only by nitrogen rate.
Species occuring at least once with RA >5 are listed.

Weed species only

Zero nitrogen

Dominant species	RA[z] Year 1	RA[z] Year 2
Agrostis hyemalis	10.4	nd
*Bidens frondosa**	7.2	nd
Cyperus dentatus	12.7	13.6
Digitaria sanguinalis	26.1	0.5
Euthamia tenuifolia ∇	5.7	10.8
Hypericum sp.	2.7	8.6
*Juncus canadensis**	5.0	6.0
*Linaria canadensis**	7.0	1.8
Muhlenbergia capallaris	nd	15.6
*Viola lanceolata**	0.7	5.2
Total number of species	27	32

Low nitrogen

Dominant species	RA Year 1	RA Year 2
A. hyemalis	8.8	nd
Ambrosia artemisiifolia	7.1	4.3
*B. frondosa**	6.3	0.2
C. dentatus	9.0	11.0
D. sanguinalis	20.2	2.9
E. tenuifolia	3.0	8.3
Hypericum sp.	3.0	7.4
Linaria canadensis	9.2	3.6
M. capallaris	nd	13.6
Panicum sp.	0.1	5.7
Total number species	32	39

Medium nitrogen

Dominant species	RA Year 1	RA Year 2
A. hyemalis	10.6	0.3
B. frondosa	6.9	0.2
C. dentatus	9.9	11.9
D. sanguinalis	19.1	3.4
E. tenuifolia ∇	5.3	10.9
Hypericum sp.*	2.7	5.3
L. canadensis	7.3	3.2
M. capallaris	nd	17.1
Panicum sp.*	0.2	5.8
*Spergularia rubrum**	5.2	0.8
Total number of species	35	38

High nitrogen

Dominant species	RA Year 1	RA Year 2
*A. artemisiifolia**	4.2	5.7
A. hyemalis	9.7	0.6
*B. frondosa**	5.3	0.6
C. dentatus	13.4	13.5
D. sanguinalis	24.1	5.4
E. tenuifolia	5.0	9.6
*L. canadensis**	6.5	4.1
M. capallaris	nd	19.5
Panicum sp.	0.7	7.8
Total number species	32	32

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each nitrogen rate.
∇ RA of this previously listed species exceeded 5% when cranberry was excluded.
* Not previously included on RA > 5% listing.

Table 4.16. Relative abundance (RA) of weed species only by vine density.
Species occuring at least once with RA >5 are listed.

Weed species only

Zero vines

Dominant species	RA[z] Year 1	RA[z] Year 2
Agrostis hyemalis	9.5	nd
Ambrosia artemisiifolia	3.7	6.2
Cyperus dentatus	11.6	10.2
Digitaria sanguinalis	22.1	2.6
Euthamia tenuifolia	4.4	9.0
Hypericum sp.	3.2	6.9
Linaria canadensis	7.1	3.4
Muhlenbergia capallaris	nd	17.2
Panicum sp.	nd	6.3
Viola lanceolata	1.7	6.5
Total number of species	32	36

Low density

Dominant species	RA Year 1	RA Year 2
*A. artemisiifolia**	6.8	4.1
A. hyemalis	8.2	0.2
*Bidens frondosa**	5.9	0.3
C. dentatus	9.0	11.3
D. sanguinalis	22.7	4.2
E. tenuifolia	3.4	9.2
L. canadensis	9.0	3.6
M. capallaris	nd	16.7
Panicum sp.*	nd	6.1
Total number species	31	37

Medium density

Dominant species	RA Year 1	RA Year 2
A. hyemalis	12.4	0.1
*B. frondosa**	6.0	nd
C. dentatus	12.6	16.4
D. sanguinalis	22.2	2.7
E. tenuifolia ∇	6.9	11.8
Hypericum sp.*	1.8	5.0
*L. canadensis**	7.5	3.2
M. capallaris	nd	17.4
*Panicum sp.**	0.7	6.3
Total number of species	34	37

High density

Dominant species	RA Year 1	RA Year 2
*A. artemisiifolia**	5.3	3.1
A. hyemalis	9.7	0.7
B. frondosa	9.0	0.1
C. dentatus	10.7	10.0
*C. strigosus**	2.9	5.1
D. sanguinalis	20.1	4.0
E. tenuifolia	4.1	10.0
Hypericum sp.*	2.9	6.5
*L. canadensis**	7.1	3.1
M. capallaris	nd	15.1
Total number species	33	38

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each vine density.
∇ RA of this previously listed species exceeded 5% when cranberry was excluded.
* Not previously included on RA > 5% listing.

Table 4.17. Relative abundance (RA) of weed species only by weed management option. Species occuring at least once with RA >5 are listed.

Weed species only

Preemergence

Dominant species	RA[z] Year 1	RA[z] Year 2
*Ambrosia artemisiifolia**	7.4	5.0
*Bidens frondosa**	7.6	nd
Cyperus dentatus	4.5	10.2
Digitaria sanguinalis ▽	19.1	6.1
Euthamia tenuifolia ▽	8.1	13.3
Hypericum gentianoides	4.3	7.4
Hypericum sp. ▽	6.8	9.6
*Linaria canadensis**	3.2	5.1
Molluga verticillata	10.6	nd
Muhlenbergia capallaris	nd	7.5
*Spergularia rubrum**	5.6	2.1
*Viola lanceolata**	1.4	5.5
Total number of species	31	35

Postemergence

Dominant species	RA Year 1	RA Year 2
*A. artemisiifolia**	5.0	4.6
B. frondosa	9.1	0.3
C. dentatus	13.1	13.2
E. tenuifolia	3.9	8.3
Hypericum sp. ▽	5.0	7.2
*Juncus canadensis**	4.8	6.7
L. canadensis	9.8	3.1
M. capallaris	nd	13.8
*S. rubrum**	5.2	2.1
*V. lanceolata**	2.9	6.3
Total number species	31	37

Inoculated

Dominant species	RA Year 1	RA Year 2
Agrostis hyemalis	14.0	0.4
*B. frondosa**	5.0	0.1
Cyperus dentatus	14.1	14.4
Digitaria sanguinalis	32.6	3.1
E. tenuifolia	3.9	11.0
Linaria canadensis	7.7	2.0
Muhlenbergia capallaris	nd	21.2
Panicum sp.	0.1	7.8
Total number of species	28	37

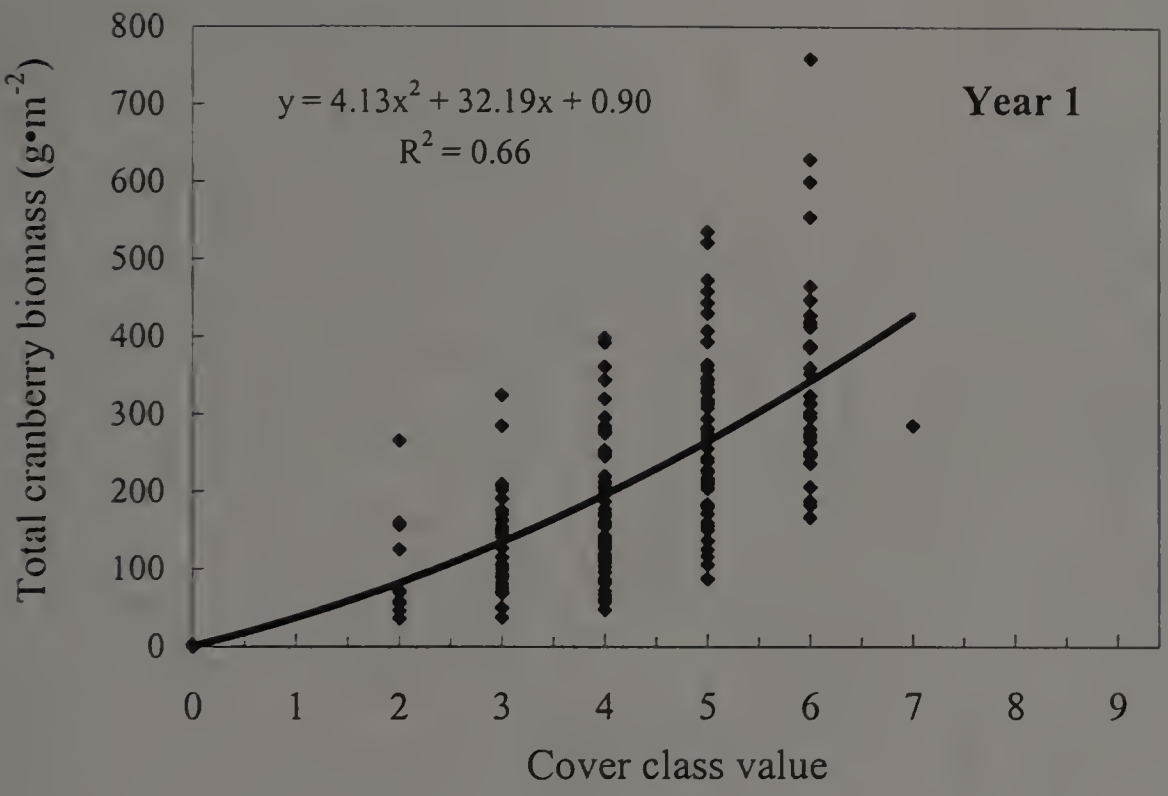
Untreated

Dominant species	RA Year 1	RA Year 2
A. hyemalis	14.1	0.4
C. dentatus	9.4	11.5
D. sanguinalis	27.3	4.1
E. tenuifolia	3.5	7.6
L. canadensis	8.0	3.6
M. capallaris	nd	21.3
Panicum sp.	0.2	9.2
Total number species	35	38

[z]Relative abundance = CCV for each species divided by the sum of all cover class values multiplied by 100 for each WMO.

▽ RA of this previously listed species exceeded 5% when cranberry was excluded.

* Not previously included on RA > 5% listing.



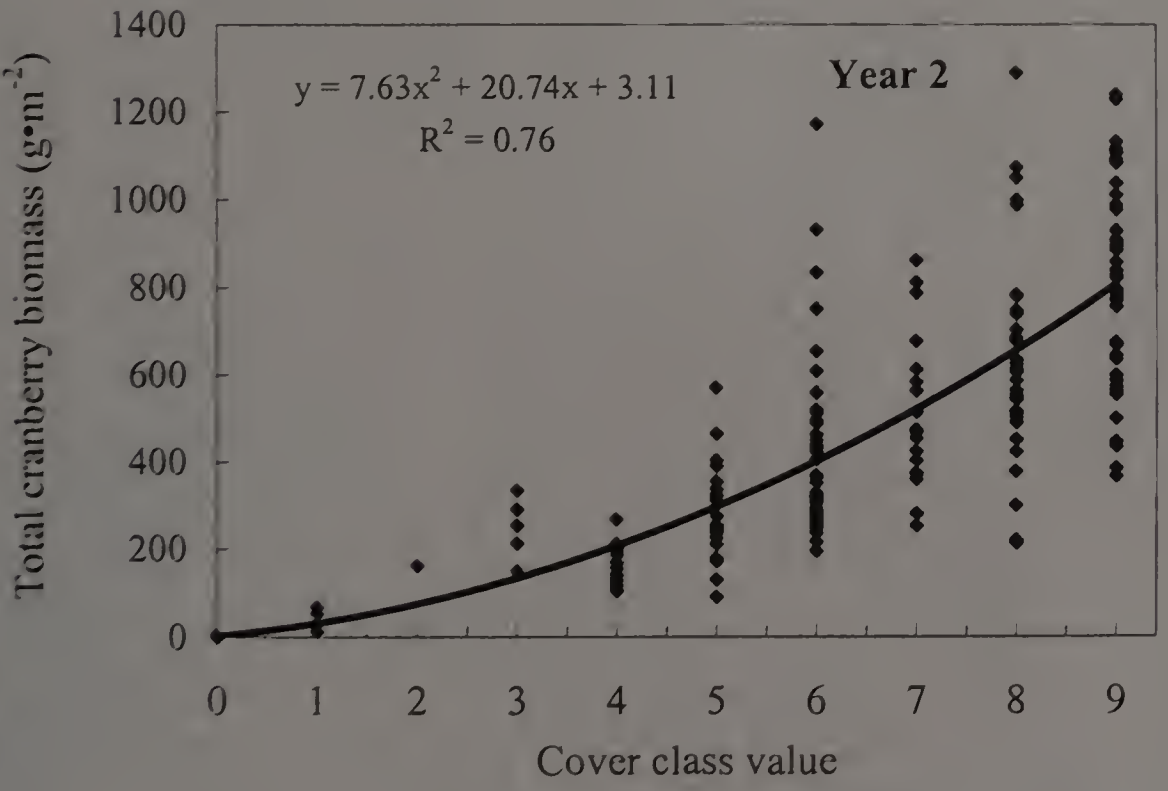


Figure 4.15. Nonlinear relationship of cranberry cover class value with total cranberry biomass in Years 1 and 2.

Table 4.18. Predicted cranberry biomass ranges for five percentage cover ranges based on cover class value and actual total cranberry biomass.

	Predicted CB biomass ($g \cdot m^{-2}$)	
Percentage cover	Year 1	Year 2
0% - 5%	0-81.8	0-75.1
6% - 25%	81.9-195.7	75.2-208.1
26% - 60%	195.8-342.7	208.2-402.2
61% - 90%	342.8-522.7	402.3-657.3
91% - 100%	522.8-625.1	657.4-807.8

N*D

Year 1

	0	28	56	112
0	< 81.8			
1.8	<195.7			
3.6		<342.7		
5.4				

Year 2

	0	28	56	112
0	<75.1			
1.8	<208.1	<402.2	<657.3	
3.6			<807.8	<807.8
5.4				

Color codes for percentage cover groupings

≤5%	
≤25%	
≤60%	
≤90%	
≤100%	
excessive	

Figure 4.16. Assignment of actual total cranberry biomass values for N*D two-way combinations into coverage groupings based on predicted biomass ranges. Numbers represent maximum predicted biomass ($g \cdot m^{-2}$) for each coverage group.

N*WMO

Year 1

	0	28	56	112
Pre	<195.7			
Post		<342.7		
Inoc				
Unt				

Year 2

	0	28	56	112
Pre	<208.1		<657.3	<807.8
Post		<402.2		
Inoc				
Unt				

Color codes for percentage cover groupings

≤5%	
≤25%	
≤60%	
≤90%	
≤100%	
excessive	

Figure 4.17. Assignment of actual total cranberry biomass values for N*WMO two-way combinations into coverage groupings based on predicted biomass ranges. Numbers represent maximum predicted biomass ($g \cdot m^{-2}$) for each coverage group.

D*WMO

Year 1

	0	1.8	3.6	5.4
Pre	**< 81.8**	**<195.7**	**<342.7**	
Post				
Inoc				
Unt				

Color codes for percentage cover groupings

≤5%	
≤25%	
≤60%	
≤90%	
≤100%	
excessive	

Year 2

	0	1.8	3.6	5.4
Pre	**<75.1**		**<807.8**	
Post			**<657.3**	
Inoc		**<402.2**		
Unt				

Figure 4.18. Assignment of actual total cranberry biomass values for D*WMO two-way combinations into coverage groupings based on predicted biomass ranges. Numbers represent maximum predicted biomass ($g \cdot m^{-2}$) for each coverage group.

0 N

	0	1.8	3.6	5.4
Pre	<81.8	<195.7	<342.7	
Post				
Inoc				
Unt				

Low N

	0	1.8	3.6	5.4
Pre				<522.7
Post				
Inoc				
Unt				

Medium N

	0	1.8	3.6	5.4
Pre				
Post				
Inoc				
Unt				

High N

	0	1.8	3.6	5.4
Pre				
Post				
Inoc				
Unt				

Color codes for percentage cover groupings

<5%	
<25%	
<60%	
<90%	
<100%	
excessive	

Figure 4.19. Year 1. Assignment of actual total cranberry biomass values for three-way combinations into coverage groupings based on predicted biomass ranges. Numbers represent maximum predicted biomass ($g \cdot m^{-2}$) for each coverage group.

0 N

	0	1.8	3.6	5.4
Pre	<75.1	<208.1		
Post			<402.2	
Inoc				
Unt				

Low N

	0	1.8	3.6	5.4
Pre			<807.8	
Post			<647.3	
Inoc				
Unt				

Medium N

	0	1.8	3.6	5.4
Pre			>807.8	
Post				
Inoc				
Unt				

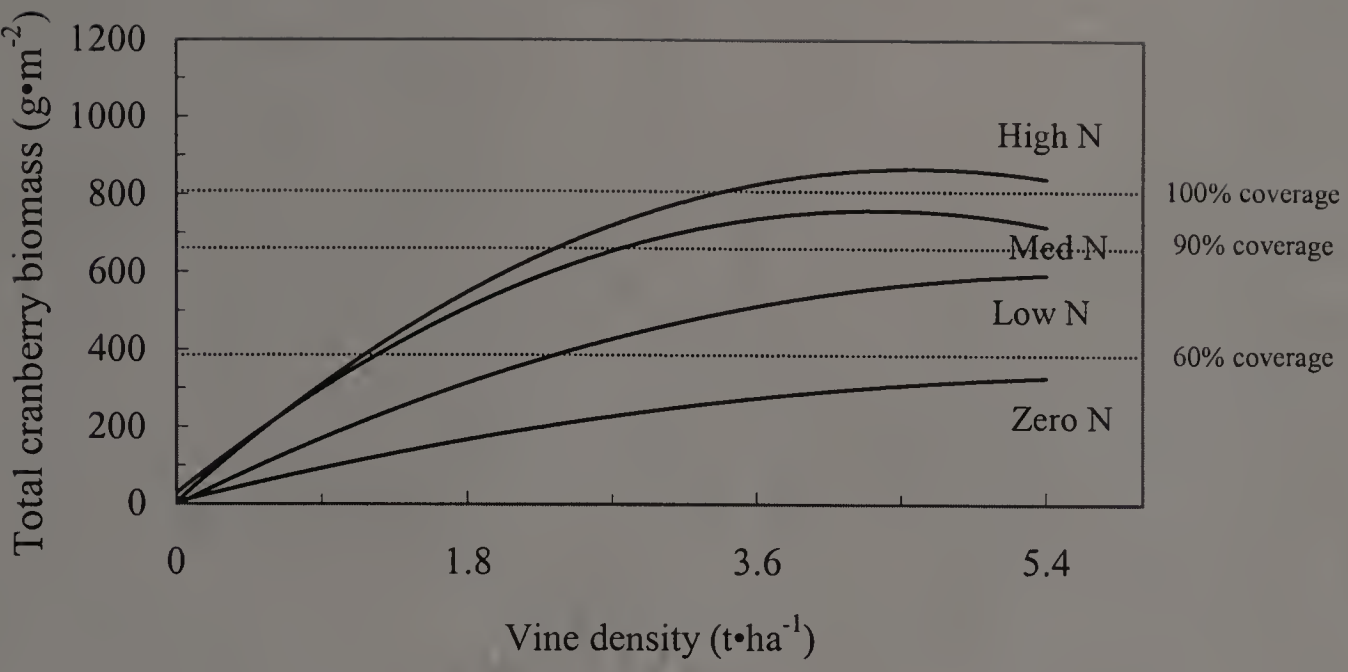
High N

	0	1.8	3.6	5.4
Pre				
Post				
Inoc				
Unt				

Color codes for percentage cover groupings

≤5%	
≤25%	
≤60%	
≤90%	
≤100%	
excessive	

Figure 4.20. Year 2. Assignment of actual total cranberry biomass values for three-way combinations into coverage groupings based on predicted biomass ranges. Numbers represent maximum predicted biomass ($g \cdot m^{-2}$) for each coverage group.



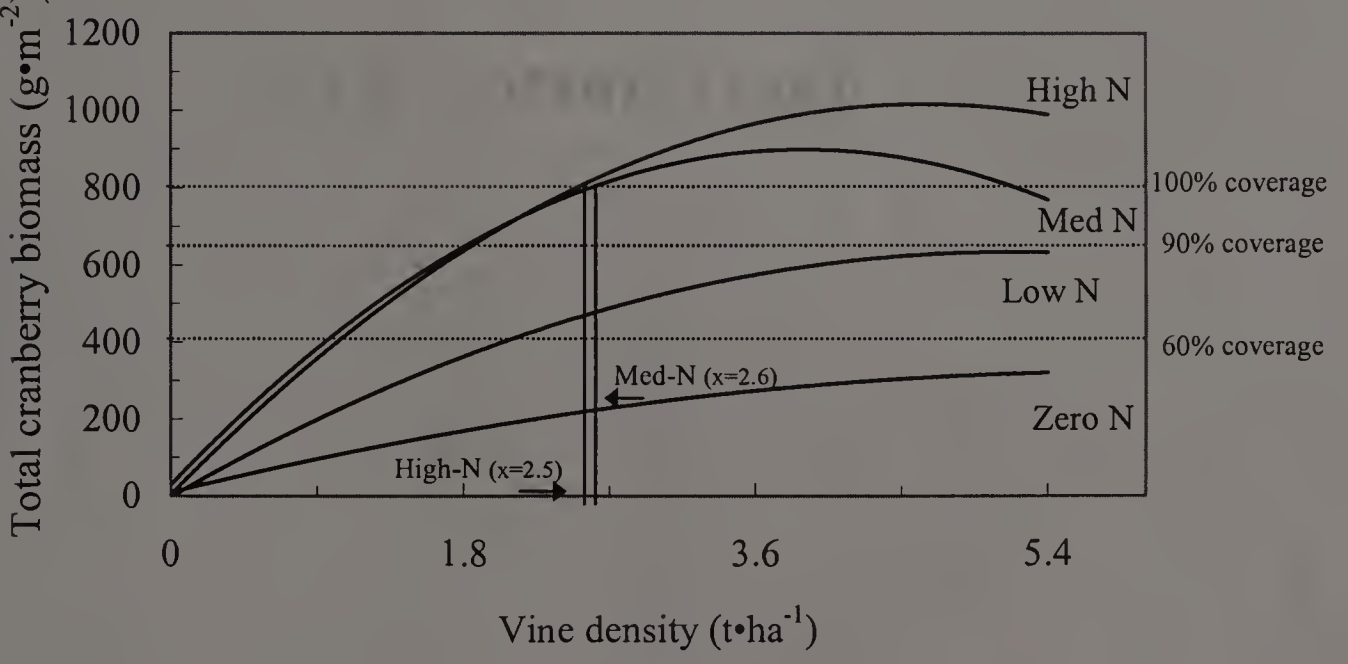
Zero N: $y = -8.4x^2 + 105.3x + 4.1$, $R^2 = 0.82$

Med N: $y = -38.6x^2 + 336.3x + 27.1$, $R^2 = 0.65$

Low N: $y = -18.2x^2 + 208.6x - 3.6$, $R^2 = 0.76$

High N: $y = -40.8x^2 + 375.4x + 4.0$, $R^2 = 0.71$

Fig. 4.21. Relationship of cranberry biomass and vine density (all treatments combined) at different nitrogen rates after two seasons of growth.



Zero N: $y = -8.8x^2 + 105.4x + 8.1$, $R^2 = 0.84$

Med N: $y = -57.5x^2 + 448.0x + 26.9$, $R^2 = 0.74$

Low N: $y = -23.8x^2 + 246.4x - 4.2$, $R^2 = 0.84$

High N: $y = -47.2x^2 + 437.9x + 1.5$, $R^2 = 0.90$

Fig. 4.22. Relationship of cranberry biomass and vine density (Pre-WMO and Post-WMO only) at different nitrogen rates after two seasons of growth.

CHAPTER 5

ECONOMIC COMPARISON OF INITIAL VINE DENSITY, NITROGEN RATE, AND WEED MANAGEMENT STRATEGY IN COMMERCIAL CRANBERRY

Introduction

The establishment of a new planting and its associated activities are among the most expensive operations performed by cranberry growers (Sandler, 1998; First Pioneer Farm Credit, 2001). The actual cost of a complete renovation project, depending on access to local materials, equipment, and labor, can range from $25K to $62K per ha (Personal communication, L. Reno, Natural Resources and Conservation Service, W. Wareham, MA). Typical activities include removal of existing vines by bulldozer, laser leveling of the bog surface (Sandler, 1998), addition of a deep sand layer (typically 10 to 20 cm), fumigation, repairing, or replacing irrigation systems, purchasing and planting of new vines, and the application of fertilizers and herbicides (DeMoranville et al., 1996; DeMoranville et al., 2001). Renovated areas are usually fumigated with either dazomet (tetrahydro-3,5-dimethyl-2H-1,3,5-thiodiazine-2-thione) or metham (methylcarbamodithioic acid) prior to planting. Vines are typically planted at densities between 2.2 to 4.4 $t \cdot ha^{-1}$, depending on cost and availability. Napropamide (N,N-diethyl-2-(1-naphthalenyloxy)propanamide) is the recommended preemergence herbicide for new plantings (DeMoranville et al., 2001). The substantial financial and time investment associated with the establishment of a new cranberry bed mandates that the grower maximize vine colonization and minimize the effects of weed competition.

Growers must make choices regarding planting density, nutrition programs, and pest management when establishing a new planting. Previous research (see Chapter 3) has provided data on the influence of nitrogen rate, weed management option, and vine planting density on cranberry and weed biomass production. What is the most economical combination of nitrogen

and vine density that provides the fastest coverage? Which integrated crop management program provides good weed control within the context of various nitrogen and planting density combinations? The objective of this study was to use data from this recent field research to calculate various parameters in order to evaluate the economic viability of vine density, nitrogen rate, and weed management schemes.

Materials and Methods

Field Study Information

Data used in this economic analysis were taken from a field study conducted in 2000-2001 at the UMass State Bog, East Wareham, MA (see Chapter 3). The following treatments were included in all combinations: 1) four nitrogen levels: 0, 28, 56, and 112 kg•ha^{-1}; 2) four vine densities: 0, 1.8, 3.6, and 5.4 metric tons (t) per hectare of the cultivar, Stevens; and 3) three weed management options: natural recruitment (no weed control), application of a preemergence herbicide, and postemergence control. The experiment was replicated four times in a randomized-complete-block-split-split-plot design.

Two comments, though mentioned previously, are brought to the reader's attention. Though not technically a measure of plant density (i.e., no. plants/unit area), the term "vine density" is commonly used in commercial cranberry production to denote the amount of vine cuttings applied to an acre (DeMoranville et al., 2001; Strik, 2002) and is used throughout the manuscript. The preemergence and postemergence treatments are two possible weed management options that cranberry growers could use in a commercial setting; inoculation with weed seeds is not typically considered a "weed management option". However, the deposition of sand or vines that contain weed seeds is a potential problem that growers might encounter in

newly planted beds (Sandler et al., 2001). For the purposes of this study, these weed treatments were collectively designated as weed management options (WMO).

Abbreviations have been used to simplify expression of treatment effects and their interactions. For the purposes of the subsequent discussion, the following abbreviations may be found in the text:

N = nitrogen rate

D = vine density

WMO = weed management option

Zero-D = 0 $t \cdot ha^{-1}$

Low-D = 1.8 $t \cdot ha^{-1}$

Med(ium)-D = 3.6 $t \cdot ha^{-1}$

High-D = 5.4 $t \cdot ha^{-1}$

Pre = preemergence treatment

Post = postemergence treatment

Unt = untreated control

Zero-N = 0 $kg \cdot ha^{-1}$

Low-N = 28 $kg \cdot ha^{-1}$

Med(ium)-N = 56 $kg \cdot ha^{-1}$

High-N = 112 $kg \cdot ha^{-1}$

Abbreviations for treatment combinations are listed by split-plot order when appropriate and separated by slashes, e.g. Low-N/Zero-D/Pre.

In both 2000 and 2001, nitrogen was applied in five equal doses of 5.6, 11.2, and 22.4 $kg \cdot ha^{-1}$, alternately as urea (46N-0P-0K) or as a complete granular fertilizer proportioned as 19N-8.2P-15.8K. Fertilizer was spread uniformly by hand across each nitrogen plot. Irrigation or rainfall typically followed application within 72 hr. During each of the initial two years of vine establishment, the total nitrogen applied to each plot was 0, 28, 56, or 112 $kg \cdot ha^{-1}$ (zero, low, medium, and high nitrogen, respectively). The plots designated to receive zero N did not receive any fertilizer inputs.

Each 32-m^2 nitrogen plot was subdivided into four density subplots (2 m x 4 m each), and each density plot was subdivided into four weed management options (WMO) plots (1 m x 2 m each). One group of subplots was treated annually with one preemergence application of

napropanuide (N,N-diethyl-2-(1-naphthalenyloxy)propanamide). We applied the active ingredient at 3.36 kg•ha^{-1} on 26 May 2000 (~ 3 wk after planting) and at 7.84 kg•ha^{-1} on 13 Apr. 2001. Each year, overhead irrigation was used (approximately 2 hr) to incorporate the herbicide into the soil.

The postemergence management plots were treated with sethoxydim (2-{1-(ethoxyimino)butyl}-5-{2-(ethylthio)propyl}-3-hydroxy-2-cyclohexen-1-one) by backpack sprayer on 26 June 2000 and 2 July 2001. Sethoxydim is a selective postemergence grass herbicide. A 1.5% solution of the herbicide plus 1% by volume crop oil concentrate was applied at a pressure of 207 kPa. In addition, these plots were hand-weeded once each year (removing any living non-cranberry biomass) approximately 1 mo after herbicide application. Time needed to remove the weeds from the Post-WMO was also recorded.

In September of each year, all above- and belowground biomass was collected from within a 900-cm^2 quadrat randomly placed in each experimental unit. Conventional hand clippers were used to cut around the entire inner perimeter of the quadrat to permit collection of cranberry runners or weeds that were passing through the quadrat. Samples were stored in brown paper bags at ambient temperatures until processed. Cranberry vines were sorted from all other plants, which were categorized as "weeds". Aboveground cranberry biomass contained both runners and uprights. The reproductive status of the uprights was not evaluated as the primary goal in a new planting is to maximize vine coverage (vegetative growth) and minimize fruit production (DeMoranville et al., 2001). Samples were oven-dried for at least 36 hr at 60°C to obtain cranberry and weed dry biomass.

Economic Assumptions

Economic estimates were calculated to permit comparisons of the treatment options in the study (Tables 5.1 and 5.2). All estimates are computed in 2002 US dollars. Nitrogen material costs were based on two applications of nitrogen at \$1.53•kg^{-1} (NPK formulation) and three

applications at $\$0.64 \cdot kg^{-1}$ (urea). Labor costs for nitrogen application were assumed to be constant across all treatments and were not included in the calculations. The cost of the N treatment was then calculated based on actual N applied. Vines costs were based on a commercial rate of $\$1{,}652 \cdot t^{-1}$ (Gilmore, 2002). Manual hand-weeding labor was estimated at $\$11 \cdot hr^{-1}$ (S. Knight, Beaton's Growers Service, W. Wareham, MA, personal communication). In 2002, napropamide cost $\$5.24 \cdot kg^{-1}$ and sethoxydim cost $\$18.94 \cdot L^{-1}$ (DeCran Agricultural Supplies, Rochester, MA, personal communication). Labor costs to apply preemergence herbicide were estimated at $50 per ha. A competent operator working on a regularly shaped, contiguous bog can cover about 5 $ha \cdot d^{-1}$ (B. Gilmore, Gilmore Cranberry Company, Carver, MA, personal communication). Postemergence herbicide product was applied at the rate of 16 $ml \cdot L^{-1}$ with an estimated coverage potential of 75 m^2 with 3.8 L of herbicide solution. The estimated cost of treating 1 ha of grass-infested bog was therefore $150.

Time to hand-weed was estimated using the data from Table 3.9. These values were halved for the economic calculations and estimations for two reasons. First, it is very probable that full-time laborers would be much faster than the scientific personnel utilized in this study. Second, biomass was being collected for subsequent analysis. Although attempts were made to just "hand-weed", extra time was likely expended to extract weeds in a fashion that would permit identification and accurate biomass evaluation. Both of these factors increased the time spent in each plot. It was assumed that paid manual laborers would have worked approximately twice as fast as the research personnel.

Results and Discussion

In Year 1, costs associated with Pre-WMO plots were directly related to vine density (Table 5.1). Pre-WMO costs for herbicide and labor were constant across all densities, so the increased costs were solely due to vine expenses. Costs in Post-WMO were more variable since

time to hand-weed varied with treatment combination (see Chapter 3). Herbicide costs were constant, so labor costs drove the price of the Post-WMO. Labor costs ranged from \$917•ha^{-1} to \$4,942•ha^{-1} in Year 1.

In Year 2, the cost of vine purchase was omitted from the estimates, and the cost differential between Pre-WMO and Post-WMO became apparent (Tables 5.1 and 5.2). The lowest labor costs associated with any Post-WMO (\$2,274•ha^{-1} in Zero-N/Med-D) were more than four times greater than all costs associated with Pre-WMO (\$461•ha^{-1}). Relative to each nitrogen/density combination, Post-WMO plots were much more expensive to maintain in Year 2 compared to Year 1. The largest increase in labor (hand-weeding) costs was in High-N/Zero-D, which was 675% higher in Year 2 compared to Year 1 (Table 1). The costs associated with hand-weeding the other High-N plots rose approximately 450% from Year 1 to Year 2. The smallest increases in postemergence control were in the Low-N/High-D and Med-N/High-D plots, where labor costs increased by 19% (\$2,926•ha^{-1} to 3,482•ha^{-1}) and 36% (\$4,942•ha^{-1} to \$6,728•ha^{-1}), respectively.

When the costs of the first two years were combined, Pre-WMO plots had lower total costs than the Post-WMO (Table 5.2). Overall, Post-WMO plots were approximately twice as expensive to manage weeds as Pre-WMO plots (values ranged from 40% to 356% increases for vine-containing plots). The Med-N/Low-D and High-N/Med-D plots were more than three times more expensive (increases of 342% and 356%, respectively) to manage with postemergence options compared to preemergence options. The smallest increase in total costs between Pre-WMO and Post-WMO was with the Zero-N/Med-D and Zero-N/High-D combinations (40% increases). Overall, the Zero-N/Low-D (\$7,695•ha^{-1}) and Zero-N/Med-D (\$9,287•ha^{-1}) plots were the least expensive vine-containing plots to manage postemergence.

The amount of money needed to produce 1 kg of cranberry biomass was calculated (Table 5.3). The total cost associated with each treatment combination was divided by the total cranberry biomass produced by the end of Year 2 in each Pre-WMO and Post-WMO plot.

Cranberry establishment was judged to be successful by both qualitative visual assessment (% cover) and quantitative biomass production, without growth becoming overly vegetative (see Chapter 4). Excessive vegetative growth (Chandler, 1961; Eck, 1971) is undesirable as the ultimate commercial goal is to produce fruit. For the purposes of this study, combinations that produced more than 807 $g \cdot m^{-2}$ were considered overly vegetative. Thus, solely in terms of sufficient (but not excessive) cranberry biomass production and good weed control, five three-way combinations were identified as effective treatments: Med-N/Med-D/Post (805 $g \cdot m^{-2}$, 90% weed reduction), Med-N/High-D/Post (758 $g \cdot m^{-2}$, 88% reduction) Med-N/Low-D/Pre (752 $g \cdot m^{-2}$, 85% reduction) Low-N/Med-D/Pre (672 $g \cdot m^{-2}$, 70% reduction) and Med-N/Low-D/Post (664 $g \cdot m^{-2}$, 80% reduction).

The most cost-effective treatment overall, in terms of maximizing cranberry biomass production while also achieving good weed control, was the Med-N/Low-D/Pre treatment (752 $g \cdot m^{-2}$, 85% reduction). One kg of cranberry biomass was produced for each 54 cents spent (Table 5.3). The next best treatment of this group in terms of cost-effectiveness was Low-N/Med-D/Pre (672 $g \cdot m^{-2}$, 70% reduction). Costs were nearly twice as high ($1.01) to produce a kilogram of cranberry biomass with this treatment combination compared to Med-N/Low-D/Pre, and weed control was poorer. High-N/Low-D/Pre and High-N/Med-D/Pre were also very efficient, with costs of $0.60 and $0.70 per kilogram cranberry biomass, respectively. However, these combinations had poorer weed control (approximately 60% weed biomass reduction) than other treatment combinations (Table 5.4). The Med-N/Low-D/Post and Med-N/High-D/Post treatments were the most expensive combinations of this group, requiring $2.83 and $2.90 for each kilogram of vines, respectively.

Unquestionably, examination of gross cranberry biomass production or weed control alone is not necessarily the only way to predict commercial success of a young planting. The criteria for successful establishment are quick and thorough coverage of the ground surface by runners (DeMoranville et al., 2001). However, fruit production is most influenced by the number

of flowering uprights and percent fruit set (Eaton and MacPherson, 1978). Once adequate ground colonization is attained, the grower must practice good horticultural techniques (e.g., frost protection, pollination, sanding) to promote the production of uprights and fruit. In commercial situations, marketable fruit is not typically gathered until the third or fourth year after establishment. Yield data were collected for this study in 2002 and yield will be collected in 2003. These data will be incorporated into future publications.

The costs associated with achieving high percentages of weed reduction were variable (Table 5.4). Costs to reduce weed biomass was calculated by determining the percentage weed reduction for Pre-WMO and Post-WMO compared to the untreated, and dividing the total cost of that treatment combination by the % weed reduction. Post-WMO combinations were successful in reducing weed biomass, but at much higher costs than the Pre-WMO. Considering three-way combinations that contained cranberry vines, costs ranged from $45 to $426 to reduce weed biomass by 1%. The cost of obtaining the best weed control (for a vine-containing combination) was fairly expensive; the Low-N/High-D/Post (98% control) needed $161 for each percent reduction in weed biomass.

Even though the Med-N/Low-D/Pre ($0.54 to produce 1 kg cranberry biomass) had less weed control (85% reduction) than many other three-way combinations, this treatment gave very cost-effective weed control ($45 for each percentage reduction) (Table 5.4). Notably, Low-N/Med-D/Pre, one of the most cost-efficient combinations at producing cranberry biomass ($\$1.01 \cdot kg^{-1}$), ranked among the lowest in terms of overall weed control (70% reduction), and was more than twice as expensive ($111 for each percentage weed reduction) as the Med-N/Low-D/Pre in terms of applying the WMO. Med-N/Med-D/Pre was fairly cost-efficient at weed reduction ($81 for each percentage weed reduction), had good weed control (85% biomass reduction), and ranked among the most cost-effective combinations in producing 1 kg of cranberry biomass ($0.79).

The best three-way combinations in terms of overall weed reduction were not necessarily the most cost-efficient at reducing weed biomass. For example, Low-N/High-D/Post and High-N/High-D/Post reduced weed biomass by 98% and 92% compared to the untreated, respectively, but at a cost of $161 and $253 for each percentage of biomass reduction, respectively. The most cost-efficient combinations for weed control (of those containing cranberry vines) were the Low-D/Pre at all N rates (less than $66); however, the High-N gave poor weed control for dollars spent (64% reduction). The Zero-N/Med-D/Pre and Med-N/Med-D/Pre combinations were also reasonably effective and cost-efficient at reducing weed biomass, costing $94 (78% reduction) and $81 (85% reduction) for each percentage reduction, respectively.

Conclusions

Based solely on the criterion of sufficient (but not excessive) cranberry biomass production, five three-way combinations gave promising forecasts for cranberry establishment: Low-N/Med-D/Pre, Med-N/Low-D/Pre, Med-N/Low-D/Post, Med-N/Med-D/Post, and Med-N/High-D/Post. These treatments had good vine coverage (without excessive vine growth) and reasonably good weed control. Low-N/Med-D/Pre and Med-N/Low-D/Pre were also very cost-efficient for producing cranberry biomass. These two treatments, as well as Med-N/Med-D/Pre, High-N/Low-D/Pre, High-N/Med-D/Pre, and High-N/High-D/Pre, could produce a kilogram of cranberry biomass for approximately one dollar or less. In spite of the vine biomass cost-efficiency, all of the High-N/Pre combinations had poor weed control and/or produced overly vegetative growth, and these combinations would be considered commercially undesirable.

While other combinations could provide positive results for growers depending on their marketing and farm management goals, the Low-D/Pre combinations were generally very cost-efficient for producing cranberry biomass and reducing weed biomass. Although the Zero-N/Low-D and the Low-N/Low-D were reasonably efficient at producing cranberry biomass, these

treatments attained less than 60% coverage of the bog surface by the end of Year 2 (see Chap.4). The Med-N/Low-D and High-N/Low-D combinations had between 90% to 100% coverage by the end of two years, but varied in weed control (85% and 64%, respectively). Synthesizing the success rates in both biological and economic terms, Med-N/Low-D/Pre ($0.54 per kg cranberry, $45 for each percentage weed reduction, and 85% weed control) was the production scheme that most cost-efficiently maximized optimal cranberry biomass production and minimized weed biomass production.

Recommendations for Growers

The data suggest that the most cost-effective production scheme for establishing a new bog is to plant vines at a low density, use moderate rates of nitrogen, and apply a yearly application of napropamide for weed control (Med-N/Low-D/Pre). This combination reduced weed biomass by 85% compared to untreated plots, and gave the best weed control per dollar spent. Though the cost of producing a kilogram of cranberry nearly doubles, the reduced nitrogen inputs of the Low-N/Med-D/Pre combination might be a viable option in areas of water quality concern. Weed control was moderate (70% reduction) with this option, and cost $111 for each percentage weed reduction. Med-N/Low-D/Post was comparable to Med-N/Low-D/Pre in terms of weed control, but it cost nearly twice as much to obtain that control.

Although the Med-N/High-D/Post combination was successful in terms of cranberry biomass production and vine coverage (90% to 100% by the end of two years), the expense of producing the vines ($2.90•ha^{-1} to produce 1 kg) diminishes the economic practicality of this treatment. Some combinations were as cost-efficient in producing cranberry biomass and applying the WMO as the Med-N/Low-D/Pre (e.g., High-N/Low-D/Pre). This treatment, however, had poorer weed control (e.g., 64% weed biomass reduction).

Post-WMO could be used in situations where growers prefer a nonchemical alternative. Costs may be slightly higher than documented in this study since a selective postemergence

herbicide was used to control a portion of the grass population. Extra labor costs would be incurred to remove any additional biomass produced by this plant group. Most growers who are considering organic production should anticipate higher operational costs than conventional cranberry growing (Sandler, 2001). Though typically minor during the first two years of establishment, additional costs for insect and disease management also need to be factored into any cost analysis.

The cost of producing a kilogram of cranberry in Med-N/Low-D/Post and the Med-N/Med-D/Post treatments ($\$2.83 \cdot kg^{-1}$ and $\$1.97 \cdot kg^{-1}$, respectively) would replace the successful Pre-WMO (costs less than $\$0.79 \cdot kg^{-1}$). In addition, the expense required to obtain weed control with these two Post-WMO combinations also becomes reasonable ($213 for each percentage reduction with 80% weed control, and $161 for each percentage reduction with 90% weed control, respectively) compared to the Pre-WMO (costs less than $81 for each percentage reduction with 85% weed control). Even with the slightly higher expenditures needed to produce cranberry biomass and control weeds with Post-WMO, the additional revenues from organic or other niche-market products may, under the right circumstances, offset the higher initial establishment costs.

This study has shown that only a small array of three-way combinations of nitrogen rate, vine density, and weed management can lead to the successful establishment of a new cranberry planting. This study evaluated the vigorous hybrid cultivar, Stevens; it is reasonable to expect that other cultivars may vary somewhat in response to vine density and nitrogen rate schemes from those reported here. Growers may need to use higher initial densities with less vigorous cultivars such as 'Early Black' and 'Howes'. The choice of a particular scheme will depend on the available local resources (e.g., vine cuttings), monetary assets, and desired farm strategies (i.e., organic vs. conventional).

Table 5.1. Estimated costs (in 2002 dollars) associated with nitrogen rate, vine density, and weed management option (WMO) treatments in Year 1 and Year 2.

Nitrogen rate ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Nitrogen costs[z] ($\$ \cdot ha^{-1}$)	Vine costs[y] ($\$ \cdot ha^{-1}$)	Year 1				Year 2			
				Pre-WMO		Post-WMO		Pre-WMO		Post-WMO	
				Labor ($\$ \cdot ha^{-1}$)	Herbicide ($\$ \cdot ha^{-1}$)	Labor ($\$ \cdot ha^{-1}$)	Herbicide ($\$ \cdot ha^{-1}$)	Labor ($\$ \cdot ha^{-1}$)	Herbicide ($\$ \cdot ha^{-1}$)	Labor ($\$ \cdot ha^{-1}$)	Herbicide ($\$ \cdot ha^{-1}$)
0	0	0	0	50	176	1,322	150	50	411	5,317	150
	1.8	0	2,974	50	176	1,360	150	50	411	3,062	150
	3.6	0	5,947	50	176	917	150	50	411	2,124	150
	5.4	0	8,920	50	176	1,513	150	50	411	2,658	150
28	0	33	0	50	176	1,673	150	50	411	6,648	150
	1.8	33	2,974	50	176	2,063	150	50	411	8,122	150
	3.6	33	5,947	50	176	1,681	150	50	411	3,884	150
	5.4	33	8,920	50	176	2,926	150	50	411	3,482	150
56	0	66	0	50	176	2,498	150	50	411	8,773	150
	1.8	66	2,974	50	176	3,422	150	50	411	9,927	150
	3.6	66	5,947	50	176	1,849	150	50	411	5,754	150
	5.4	66	8,920	50	176	4,942	150	50	411	6,728	150
112	0	132	0	50	176	1,192	150	50	411	9,224	150
	1.8	132	2,974	50	176	978	150	50	411	5,515	150
	3.6	132	5,947	50	176	3,881	150	50	411	21,047	150
	5.4	132	8,920	50	176	2,192	150	50	411	11,615	150

[z]Nitrogen costs are the same for Year 1 and Year 2.

[y]Vines costs are expended in Year 1 only.

Table 5.2. Total costs (in 2002 dollars) associated with nitrogen rate, vine density, and weed management option (WMO) treatments.

Nitrogen rate ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Year 1[z] Costs ($\$ \cdot ha^{-1}$)		Year 2 Costs ($\$ \cdot ha^{-1}$)		Total Costs ($\$ \cdot ha^{-1}$)	
		Pre	Post	Pre	Post	Pre	Post
0	0	226	1,472	461	5,467	687	6,938
	1.8	3,200	4,484	461	3,212	3,661	7,695
	3.6	6,173	7,014	461	2,274	6,634	9,287
	5.4	9,146	10,583	461	2,808	9,607	13,391
28	0	259	1,856	494	6,831	753	8,687
	1.8	3,233	5,220	494	8,305	3,727	13,524
	3.6	6,206	7,811	494	4,067	6,700	11,878
	5.4	9,179	12,029	494	3,665	9,673	15,694
56	0	292	2,714	527	8,989	819	11,703
	1.8	3,266	6,612	527	10,143	3,793	16,755
	3.6	6,239	8,012	527	5,970	6,766	13,981
	5.4	9,212	14,078	527	6,944	9,739	21,023
112	0	358	1,474	593	9,506	951	10,980
	1.8	3,332	4,234	593	5,797	3,925	10,031
	3.6	6,305	10,110	593	21,329	6,898	31,439
	5.4	9,278	11,394	593	11,897	9,871	23,292

[z]Vines costs accounted for in Year 1.

Table 5.3. Cranberry biomass produced in Pre-WMO and Post-WMO combinations at the end of two years, and cost to produce a kilogram of cranberry biomass. Values are the mean of 4 replicates.

Nitrogen rate ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Cranberry biomass ($g \cdot m^{-2}$)		Cost to produce 1 kg CB biomass ($)	
		Pre-WMO	Post-WMO	Pre-WMO	Post-WMO
0	0	0	0	0	0
	1.8	185	201	2.15	3.97
	3.6	232	268	3.64	3.52
	5.4	324	334	3.02	4.16
28	0	0	0	0	0
	1.8	368	331	1.10	4.60
	3.6	672	494	1.01	2.49
	5.4	625	632	1.62	2.56
56	0	13	0	0.40	0
	1.8	752	664	0.54	2.83
	3.6	864	805	0.79	1.97
	5.4	820	758	1.42	2.90
112	0	0	0	0	0
	1.8	699	583	0.60	1.73
	3.6	1004	918	0.70	3.64
	5.4	1020	961	0.99	2.44

Thin-bordered boxes indicate combinations previously identified as efficient for cranberry biomass production and weed reduction.

Heavy-bordered boxes indicate most cost-efficient combinations for producing cranberry biomass (not included in the first group).

Table 5.4. Weed biomass production in Pre-WMO, Post-WMO, and Unt-WMO combinations at the end of two years, % weed reduction, and costs to reduce weed biomass by 1 percent. Values are the mean of 4 replicates.

Nitrogen rate ($kg \cdot ha^{-1}$)	Vine density ($t \cdot ha^{-1}$)	Weed biomass ($g \cdot m^{-2}$)			Weed reduction (%)		Cost to reduce weed biomass by 1%	
		Pre-WMO	Post-WMO	Unt-WMO	Pre	Post	Pre	Post
0	0	37	48	167	76	70	9	116
	1.8	15	10	48	51	77	101	105
	3.6	8	4	117	78	91	94	104
	5.4	21	7	102	74	92	162	147
28	0	122	31	425	70	91	13	96
	1.8	91	42	441	77	92	50	147
	3.6	72	17	218	70	94	111	127
	5.4	39	7	351	89	98	110	161
56	0	458	72	564	19	88	28	134
	1.8	65	77	426	85	80	45	213
	3.6	55	30	422	87	90	81	161
	5.4	88	49	470	76	88	141	245
112	0	396	45	1464	76	96	13	114
	1.8	267	64	641	64	89	66	114
	3.6	226	58	579	61	82	165	426
	5.4	140	30	417	68	92	173	253

Heavy-bordered boxes indicate top two cost-efficient weed reduction combinations for Pre-WMO and Post-WMO (containing cranberry vines).

CHAPTER 6

DISSERTATION SUMMARY

In this research, the interaction of various horticultural practices on cranberry biomass production, cranberry yield components, plant species community composition (abundance and frequency of identified plant species) and weed control was examined. One study explored the effects of four years of repeat annual applications of three rates of dichlobenil, a preemergence herbicide, on cranberry biomass production, yield components, and weed control. The second study examined the interaction of four nitrogen rates, four vine densities, and four weed management options in the establishment of new cranberry plantings. In addition to documenting crop and weed biomass production, both studies included the collection of vegetation survey data to assess the effect of treatment on plant species composition.

Cranberry growers have expressed concern that long-term use of dichlobenil was detrimental to the productivity of the cranberry plant and negatively affected yield. This work demonstrated that repeated annual herbicide application did not adversely affect any yield parameters, upright productivity, biomass production, or percentage fruit set. Treatment effects on cranberry root length were mixed and varied by sampling date. No consistent trend could be described. Further work is needed to determine if herbicide application and/or weed density adversely or positively affects cranberry root length.

Results from this study suggest that growers could use either low or high end rates of dichlobenil without detrimental impact on crop productivity and yield. However, growers should exercise caution if other factors are present that cause plant stress, such as drought or pest injury. Though often attributed to herbicide application alone, the combination of chronic physiological stress and herbicide applications are often responsible for inducing signs of vine stress. For example, yellow vine syndrome may be associated with poor water management and herbicide

stress (DeMoranville et al., 1999). With this caution in mind, repeat annual applications of dichlobenil may be considered as part of a realistic integrated weed management program with minimal long-term risk.

In the new planting study, cranberry biomass production was influenced by WMO; using either preemergence or postemergence weed management significantly increased cranberry biomass compared to untreated or inoculated plots. Planting at densities greater than 3.6 $t \cdot ha^{-1}$ did not improve cranberry biomass production when at least low rates of N were applied. Since the Post-WMO plots received mid to late-season hand weeding, the Post-WMO treatment gave superior weed control compared to the other WMO. When weeds were controlled, vine density did not influence weed biomass production. However, when weeds were left untreated, vine density reduced the production of weed biomass when N was highly abundant. Even though weed biomass was reduced, the reduction was not to a level that would be considered commercially acceptable.

Fifty-five different weed species were identified during the first 2 years of establishment. No single treatment alone affected the measured vegetation parameters. Nitrogen rate, vine density, and WMO interacted to affect % occurrence, % frequency, and relative abundance of plant species that colonized the new cranberry planting. The plant community documented in this study is distinctive for this location, and other farms will likely have different initial plant communities than the community described herein. Thus, scouting should be employed to identify plant species to promote efficient weed management in new cranberry plantings.

Even though the exact species composition and relative abundance varied from treatment to treatment, several species were considered abundant over the course of the study: *Agrostis hyemalis* (Year 1), *Euthamia tenuifolia* (Y1 and Y2), *Ambrosia artemisiifolia* (Y1), *Hypericum sp.* (Y2), *Bidens frondosa* (Y1), *Linaria canadensis* (Y1), *Cyperus dentatus* (Y1 & Y2), *Muhlenbergia capallaris* (Y2), *Digitaria sanguinalis* (Y1), and *Panicum sp.* (Y2).

When used in conjunction with weed management, low initial densities could produce substantial cranberry coverage in two years. Med-N and High-N weed control combinations achieved 100% coverage with initial planting densities of 2.6 and 2.5 $t \cdot ha^{-1}$, respectively. Moreover, both Med-N and High-N weed control combinations achieved 90% coverage with an initial planting density of 1.8 $t \cdot ha^{-1}$. In conclusion, growers could use low initial vine densities (1.8 $t \cdot ha^{-1}$) with Med-N or High-N applications with a weed management program (either preemergence or postemergence) and expect to achieve 90% cranberry vine coverage after two years of growth. Use of an additional 0.5 to 1.0 $t \cdot ha^{-1}$ at planting could achieve 100% coverage at the end of two years, but would require at least \$800 to \$1,000$\cdot ha^{-1}$ as added initial costs.

This study evaluated the vigorous hybrid, Stevens; it is reasonable to expect that other cultivars may vary in response to vine density and nitrogen rate schemes from those reported here. Growers may need to us higher initial densities with less vigorous varieties such as 'Early Black' or 'Howes'. Data from this study should provide a practical guideline for establishing new plantings as it is anticipated that many growers will opt to re-plant with either 'Stevens' or new hybrids. For most growers, the used of preemergence and postemergence weed control options are not mutually exclusive, and an integrated weed management plan will likely be used.

This study has shown that only a small array of three-way combinations of nitrogen rate, vine density, and weed management can lead to the successful establishment of a new cranberry planting. Based on cranberry biomass production and weed control, Med-N/Med-D/Post, Med-N/High-D/Post, Med-N/Low-D/Pre, Low-N/Med-D/Pre, and Med-N/Low-D/Post treatment combinations gave promising results. Economic analysis suggested that the most cost-effective production scheme for establishing a new bog is to plant vines a low density, use moderate rates of nitrogen, and apply a yearly application of napropamide for weed control (Med-N/Low-D/Pre). This combination efficiently produced optimal vine coverage, reduced weed biomass by 85% compared to untreated plots, and gave the best weed control per dollar spent.

APPENDIX A
STATISTICAL SUMMARY TABLES FOR CHAPTER 2

Appendix A.1. Summary of ANOVA for spring uprights.
Numbers are P-values from analyses. NS = P>0.10.

Measured variable	Site	Site*Year	Site*Weed	Site*Herb	Site*Weed*Herb
Spring Uprights					
Total upright-old growth	<0.001	0.044	NS	NS	0.080
% Flowering-new growth	<0.001	<0.001	NS	NS	NS
Total upright-new growth	<0.001	0.012	NS	NS	0.042
Leaf dry biomass	0.027	0.005	NS	NS	NS
Change in upright density	0.002	0.030	NS	NS	NS

Measured variable	Year	Year*Weed	Year*Herb
Spring Uprights			
Total upright-old growth	0.001	NS	NS
% Flowering-new growth	<0.001	0.038	NS
Total upright-new growth	NS	NS	NS
Leaf dry biomass	<0.001	0.050	NS
Change in upright density	0.001	NS	NS

Measured variable	Weeds	Herbicide	Weed*Herb
Spring Uprights			
Total upright-old growth	NS	0.072	NS
% Flowering-new growth	0.004	NS	NS
Total upright-new growth	NS	0.035	NS
Leaf dry biomass	NS	NS	NS
Change in upright density	0.037	NS	NS

Table A.2. Summary of ANOVA for fall uprights.
Numbers are P-values from analyses. NS = P>0.10.

Measured variable	Site	Site*Year	Site*Weed	Site*Herb	Site*Weed*Herb
Fall Uprights					
% Flowering	0.001	0.016	NS	NS	NS
Total uprights	<0.001	NS	0.012	NS	NS
% Fruit set	0.001	0.010	0.035	NS	NS
No. terminal buds	0.004	0.006	NS	0.039	NS
Leaf dry biomass	<0.001	NS	0.035	NS	NS

Measured variable	Year	Year*Weed	Year*Herb
Fall Uprights			
% Flowering	NS	0.061	NS
Total uprights	NS	0.011	NS
% Fruit set	<0.001	NS	NS
No. terminal buds	0.002	0.047	NS
Leaf dry biomass	0.001	0.024	NS

Measured variable	Weeds	Herbicide	Weeds*Herb
Fall Uprights			
% Flowering	NS	NS	NS
Total uprights	NS	NS	NS
% Fruit set	NS	NS	NS
No. terminal buds	NS	NS	NS
Leaf dry biomass	NS	NS	NS

Table A.3. Summary of ANOVA for harvest parameters.
Numbers are P-values from analyses. NS = P>0.10.

Measured variable	Site	Site*Year	Site*Weed	Site*Herb	Site*Weed*Herb
Harvest parameters					
Wt per berry healthy	<0.001	0.011	NS	NS	NS
% Unusable yield	0.023	<0.001	0.038	NS	NS
Usable yield	0.001	<0.001	0.057	NS	NS
Total yield	0.032	<0.001	NS	NS	NS

Measured variable	Year	Year*Weed	Year*Herb
Harvest parameters			
Wt per berry healthy	<0.001	NS	NS
% Unusable yield	<0.001	0.044	NS
Usable yield	<0.001	NS	NS
Total yield	<0.001	NS	NS

Measured variable	Weeds	Herbicide	Weed*Herb
Harvest parameters			
Wt per berry healthy	NS	NS	NS
% Unusable yield	0.065	NS	NS
Usable yield	0.001	NS	NS
Total yield	0.001	NS	NS

Table A.4. Summary of ANOVA for vegetation surveys.
Numbers are P-values from analyses. NS = P>0.10.

Measured variable	Site	Site*Year	Site*Weed	Site*Herb	Site*Weed*Herb
Survey parameters					
%Cover	0.002	NS	NS	NS	NS
Species richness	0.005	NS	0.060	NS	NS
Diversity (H')	0.009	NS	0.045	NS	NS
% Change weed cover	NS	n/a	NS	NS	NS

Measured variable	Year	Year*Weed	Year*Herb
Survey parameters			
%Cover	<0.001	0.009	NS
Species richness	<0.001	0.086	NS
Diversity (H')	<0.001	NS	NS
% Change weed cover	n/a	n/a	n/a

Measured variable	Weeds	Herbicide	Weed*Herb
Survey parameters			
%Cover	<0.001	NS	NS
Species richness	0.003	0.049	NS
Diversity (H')	0.010	0.100	NS
% Change weed cover	0.047	NS	NS

Table A.5. Summary of ANOVA for cranberry and alfalfa (bioassay) root lengths. Numbers are P-values from analyses. NS = P>0.10.

Measured variable	Site	Site*Year	Site*W	Site*Herb	Site*W*H
CB root length	NS	n/a	NS	NS	NS
Alfalfa root length	NS	0.027	NS	0.058	0.093

Measured variable	Year	Year*W	Year*H	Year*Date
CB root length	n/a	n/a	n/a	n/a
Alfalfa root length	<0.001	NS	0.020	<0.001

Measured variable	Date[z]	Date*W	Date*H	Date*Site	Date*W*H
CB root length	<0.001	0.097	0.086	0.010	0.011
Alfalfa root length	<0.001	NS	0.091	0.017	NS

Measured variable	Weeds	Herbicide	W*H
CB root length	0.063	0.084	0.073
Alfalfa root length	NS	<0.001	NS

[z]Sampling date for cranberry root length is 3 dates in 2 years. Sampling date for alfalfa root length is up to 6 times per annum.

Dunnetts P-values	Alfalfa root lengths					
1998	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6
Low-rate herbicide	n/a	NS	0.041	NS	NS	NS
High-rate herbicide	0.005	NS	0.001	0.001	0.061	NS
1999						
Low-rate herbicide	n/a	0.031	0.024	NS	NS	n/a
High-rate herbicide	<0.001	0.001	0.009	0.020	NS	n/a
2000						
Low-rate herbicide	0.003	NS	0.059	0.082	NS	NS[z]
High-rate herbicide	0.001	0.001	NS	0.017	0.058	0.022
2001						
Low-rate herbicide	NS	n/a	NS	0.030	NS	NS
High-rate herbicide	NS	0.001	0.002	NS	0.098	0.066

[z]Data for CVR only for Date 6 in 2000.

Table A.6. Summary of ANOVA for significant site*treatment interactions. Numbers are P-values from analyses. NS = P>0.10.

CVR

Measured variable	Weeds	Herbicide	W*H	Year	W*Y	H*Y
Spring Uprights						
Total upright-new growth	NS	0.072	0.022	0.073	NS	NS
Fall Uprights						
Total upright	NS	NS	NS	NS	NS	NS
% Fruit set	0.014	NS	NS	<0.001	NS	NS
No. terminal buds	NS	0.097	0.057	0.002	NS	0.001
Leaf dry biomass	0.029	NS	NS	0.024	0.012	NS
Harvest parameters						
% Unusable yield	0.010	NS	NS	<0.001	NS	NS
Survey parameters						
Diversity index	0.012	NS	NS	0.001	NS	NS

RCH

Measured variable	Weeds	Herbicide	W*H	Year	W*Y	H*Y
Spring Uprights						
Total upright-new growth	NS	NS	NS	0.041	0.085	NS
Fall Uprights						
Total upright	0.061	NS	NS	NS	0.046	NS
% Fruit set	NS	NS	NS	0.008	NS	NS
No. terminal buds	0.023	NS	NS	NS	0.015	NS
Leaf dry biomass	NS	NS	NS	0.006	NS	NS
Harvest parameters						
% Unusable yield	NS	NS	NS	0.000	0.063	0.029
Survey parameters						
Diversity index	NS	NS	NS	<0.001	NS	NS

APPENDIX B

PLOT DESIGN AND STATISTICAL SUMMARY TABLES FOR CHAPTER 3

Figure B.1. Schematic of experimental plot design.

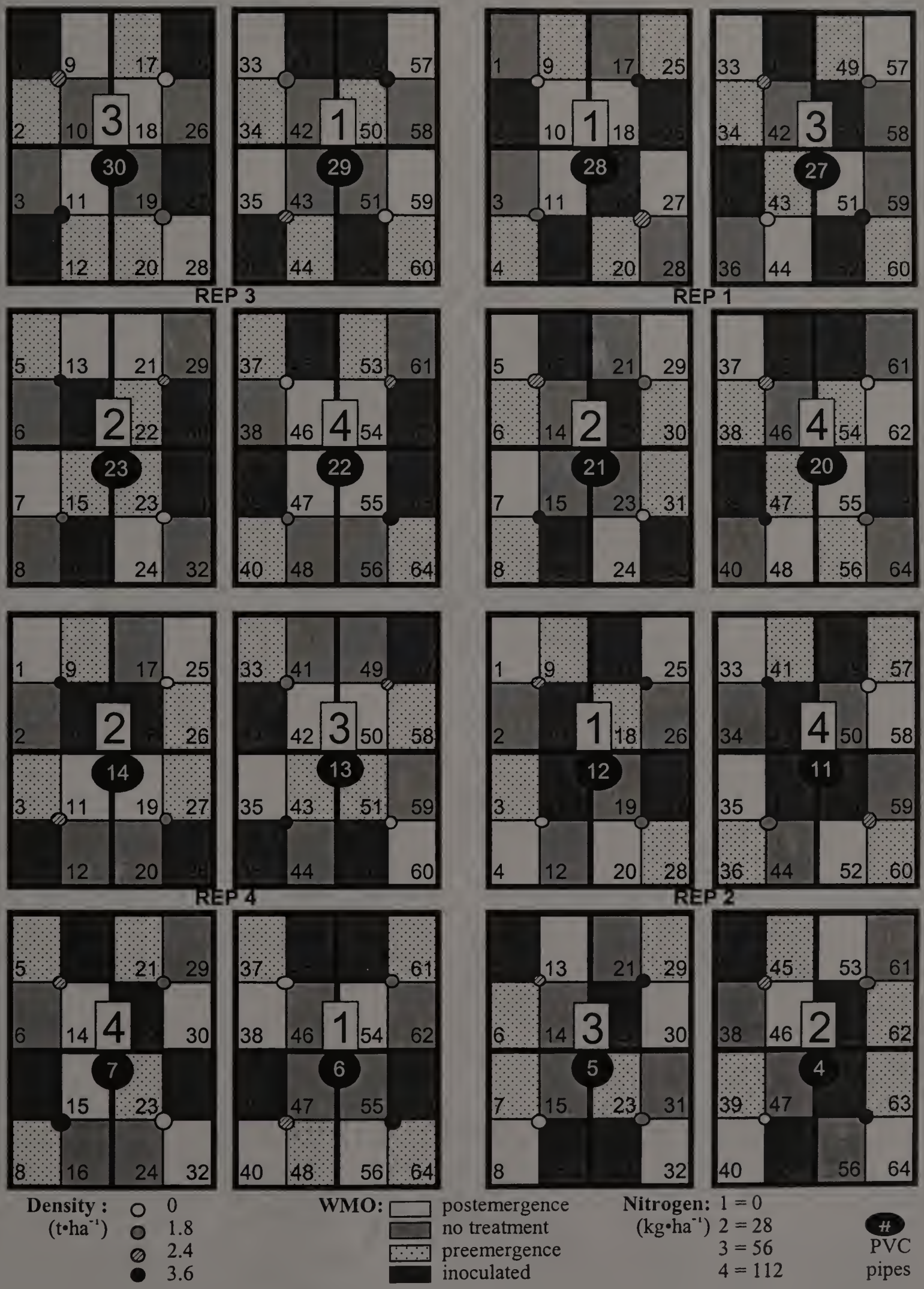


Table B.2. Summary of P-values from ANOVA for pre- and postemergence treatments including year interactions. NS = P>0.10.

Measured variable	Nitrogen	Density	N*D	Year	N*Y	D*Y	N*D*Y
Pre-emergence							
Number of shoots	0.008	NS	NS	0.017	NS	NS	NS
Stem length	0.039	NS	NS	NS	0.091	NS	NS
Grass stem weight	0.033	NS	NS	0.049	NS	0.060	NS
Grass root weight	NS	NS	NS	0.063	NS	0.039	NS
Postemergence							
Number BL plants	NS	0.005	NS	0.025	0.062	0.005	NS
BL stem weight	NS	NS	NS	NS	NS	NS	NS
BL root weight	0.060	0.046	NS	NS	NS	NS	NS
Number grass plants	0.001	0.001	NS	<0.001	<0.001	0.003	NS
Grass stem weight	0.003	0.006	NS	0.002	<0.001	0.010	NS
Grass root weight	0.021	0.008	NS	0.004	0.006	0.045	NS
Number of rushes	NS	0.078	NS	NS	NS	NS	NS
Rush stem weight	NS	NS	NS	0.051	NS	NS	NS
Rush root weight	NS	NS	NS	0.046	NS	NS	NS
Number of sedges	0.099	NS	0.087	0.017	0.041	NS	NS
Sedge stem weight	0.023	NS	0.003	0.029	0.030	NS	NS
Sedge root weight	0.037	NS	NS	NS	NS	NS	NS
Σ BL root & stem	NS	0.024	NS	NS	0.047	NS	NS
Σ Grass root & stem	0.001	<0.001	NS	0.001	<0.001	<0.001	NS
Σ Rush root & stem	NS	NS	NS	0.057	NS	NS	NS
Σ Sedge root & stem	0.021	NS	0.011	0.048	0.017	NS	NS
Total number plants	0.064	0.004	NS	0.017	0.009	0.023	NS
Total stem biomass	0.005	0.001	NS	0.040	0.003	0.002	NS
Total root biomass	0.015	0.003	NS	NS	NS	NS	NS
% BL	NS	NS	NS	0.011	0.046	NS	NS
% Grass	NS	0.008	NS	0.001	0.003	0.067	NS
% Rush	NS	NS	NS	0.036	NS	NS	NS
% Sedge	NS	0.041	NS	NS	NS	NS	NS
Time	0.027	NS	<0.001	0.013	0.018	0.039	0.022

Table B.3. Summary of P-values from ANOVA for pre- and postemergence treatments by year. NS = P>0.10.

	2000			2001		
Measured variable	Nitrogen	Density	N*D	Nitrogen	Density	N*D
Pre-emergence						
Grass root weight	NS	NS	NS	0.004	0.040	NS
Postemergence						
Number BL plants	NS	NS	NS	NS	0.001	NS
Number grass plants	NS	NS	NS	<0.001	<0.001	NS
Grass stem weight	NS	NS	NS	0.001	0.010	NS
Grass root weight	NS	NS	NS	0.009	0.014	NS
Number of sedges	NS	NS	NS	0.034	0.075	NS
Σ BL root & stem	0.091	NS	NS	0.028	0.002	NS
Σ Grass root & stem	NS	NS	NS	<0.001	<0.001	NS
Total number plants	NS	NS	NS	<0.001	<0.001	NS
Total stem biomass	NS	NS	NS	<0.001	<0.001	0.033
% Grass	NS	NS	NS	0.023	0.001	NS
Time	NS	NS	0.022	0.002	NS	<0.001

Table B.4. Summary of P-values from ANOVA for end-of-season bimass, including year interactions. NS = P>0.10.

Measured variable	Nitrogen	Density	Weed option	Year
CB stem weight	<0.001	<0.001	0.003	<0.001
CB root weight	NS	<0.001	0.014	NS
Total CB biomass	0.001	<0.001	0.003	0.001
Weed stem weight	<0.001	0.008	<0.001	NS
Weed root weight	0.001	0.010	<0.001	0.043
Total weed biomass	<0.001	0.005	<0.001	NS
%CB-aboveground	0.047	<0.001	<0.001	0.008
%CB-belowground	0.084	<0.001	<0.001	NS
%CB of total biomass	0.059	<0.001	<0.001	0.017

Measured variable	N*D	N*W	D*W	N*D*W	N*D*W*Y
CB stem weight	<0.001	NS	NS	NS	NS
CB root weight	NS	NS	0.041	NS	NS
Total CB biomass	<0.001	NS	NS	NS	NS
Weed stem weight	NS	<0.001	NS	0.043	NS
Weed root weight	NS	<0.001	NS	NS	NS
Total weed biomass	NS	0.001	NS	0.041	NS
%CB-aboveground	0.020	0.029	<0.001	NS	NS
%CB-belowground	0.057	NS	<0.001	NS	NS
%CB of total biomass	0.022	0.024	<0.001	NS	NS

Measured variable	N*Y	D*Y	W*Y	N*D*Y	N*W*Y	D*W*Y
CB stem weight	<0.001	<0.001	NS	0.002	NS	NS
CB root weight	NS	NS	NS	0.094	NS	NS
Total CB biomass	0.000	<0.001	NS	0.009	NS	NS
Weed stem weight	0.028	0.043	0.039	NS	NS	NS
Weed root weight	NS	0.014	NS	NS	NS	NS
Total weed biomass	0.046	0.032	0.091	NS	NS	NS
%CB-aboveground	NS	0.003	0.001	NS	NS	0.044
%CB-belowground	NS	NS	NS	0.035	NS	NS
%CB of total biomass	NS	0.040	0.003	NS	NS	NS

Table B.5. Summary of P-values from ANOVA for harvest biomass by year. NS = P>0.10.

2000

Measured variable	N	D	Weed option	N*D	N*W	D*W	N*D*W
Harvest biomass							
CB stem weight	0.064	<0.001	0.012	0.013	NS	0.098	NS
Total CB biomass	NS	<0.001	0.017	0.054	NS	0.097	NS
Weed stem weight	0.003	NS	<0.001	NS	0.009	NS	0.024
Weed root weight	0.019	0.008	<0.001	NS	0.005	NS	NS
Total weed biomass	0.004	0.042	<0.001	NS	0.007	NS	0.060
%CB-aboveground	0.050	<0.001	<0.001	NS	0.034	<0.001	NS
%CB-belowground	NS	<0.001	<0.001	NS	NS	<0.001	NS
%CB total biomass	0.066	<0.001	<0.001	NS	0.029	<0.001	NS

2001

Measured variable	N	D	Weed option	N*D	N*W	D*W	N*D*W
Harvest biomass							
CB stem weight	<0.001	<0.001	0.006	<0.001	NS	NS	NS
Total CB biomass	<0.001	<0.001	0.005	<0.001	NS	NS	NS
Weed stem weight	<0.001	0.002	<0.001	NS	0.003	0.026	NS
Weed root weight	0.000	0.016	<0.001	NS	0.036	NS	NS
Total weed biomass	<0.001	0.003	<0.001	NS	0.020	0.017	NS
%CB-aboveground	0.033	<0.001	<0.001	0.012	NS	<0.001	NS
%CB-belowground	0.053	<0.001	<0.001	0.003	NS	<0.001	NS
%CB total biomass	0.052	<0.001	<0.001	0.003	0.042	<0.001	NS

Table B.6. Summary of P-values from ANOVA for light penetration (date interactions) and light penetration by date. NS = P>0.10.

Measured variable	N	D	Weed option	Date	N*D	N*W	D*W
% penetration	<0.001	<0.001	<0.001	<0.001	0.024	<0.001	NS

Measured variable	N*D*W	N*date	D*date	W*date	N*D*date	N*W*date
% penetration	NS	<0.001	0.004	<0.001	0.024	<0.001

Measured variable	D*W*date	N*D*W*date
% penetration	<0.001	NS

2000

Measured variable	N	D	Weed option	N*D	N*W	D*W	N*D*W
%penetration-July	0.005	0.001	0.001	NS	0.026	NS	0.025
%penetration-Aug	<0.001	NS	<0.001	0.021	<0.001	NS	NS

2001

Measured variable	N	D	Weed option	N*D	N*W	D*W	N*D*W
%penetration-July	<0.001	<0.001	0.002	NS	NS	NS	NS
%penetration-Aug	<0.001	<0.001	<0.001	0.031	<0.001	<0.001	0.084

Table B.7. Summary of P-values from ANOVA for cranberry tissue analysis.
NS = P>0.10.

Measured variable	Nitrogen	Weeds	Year	N*W	N*Y	W*Y	N*W*Y
Nitrogen	<0.001	NS	0.042	NS	0.014	NS	NS
Phosphorus	<0.001	0.065	NS	NS	<0.001	NS	NS
Potassium	<0.001	0.005	0.003	0.015	NS	NS	NS
Calcium	<0.001	0.010	0.014	0.059	0.018	NS	NS
Magnesium	<0.001	0.031	0.025	NS	NS	NS	NS
Zinc	<0.001	0.021	NS	NS	<0.001	NS	NS
Copper	NS	NS	0.014	NS	NS	NS	NS
Manganese	0.001	0.040	NS	NS	NS	NS	0.043
Iron	<0.001	NS	0.011	NS	NS	NS	NS
Boron	<0.001	0.017	0.059	NS	0.010	NS	NS
Aluminum	<0.001	NS	NS	0.064	NS	NS	NS

2000

Measured variable	Nitrogen	Weeds	N*W
Nitrogen	<0.001	NS	NS
Phosphorus	<0.001	NS	NS
Calcium	0.001	0.013	NS
Zinc	0.048	0.092	NS
Boron	<0.001	0.012	NS

2001

Measured variable	Nitrogen	Weeds	N*W
Nitrogen	<0.001	NS	NS
Phosphorus	0.001	0.097	0.026
Calcium	<0.001	0.014	0.036
Zinc	<0.001	0.034	NS
Boron	<0.001	0.038	NS

Table B.8. Summary of P-values from ANOVA for water nitrogen analysis.
NS = P>0.10.

Measured variable	Nitrogen	Year	Date	N*Y	N*Date	Y*Date	N*Y*Date
Nitrate-nitrogen	NS	NS	0.043	NS	NS	NS	NS
Ammonia-nitrogen	NS	0.019	<0.001	NS	NS	<0.001	NS
Total nitrogen	NS	0.016	<0.001	NS	NS	<0.001	NS

Table B.9. Summary of P-values from orthogonal polynomial constrasts for weed biomass parameters for plots treated pre- and postemergence. NS = P>0.10.

Preemergence

Measured variable	First 2 years		
	Nitrogen		
	linear	quadratic	cubic
Stem length	0.010	0.098	NS
Grass stem weight	0.003	NS	NS
No. shoots	0.005	0.027	NS

Postemergence

	Nitrogen		
	linear	quadratic	cubic
Sedge root weight	0.001	NS	NS
Total root biomass	0.014	0.017	NS

Postemergence

Measured variable	First 2 years		
	Density		
	linear	quadratic	cubic
BL root weight	0.005	0.017	0.065
Σ BL root & stem	0.008	0.023	NS
Total root biomass	<0.001	0.001	0.053
% Grass	0.002	NS	NS
% Sedge	0.020	0.038	NS

Table B.10. *Year 2*. Summary of P-values from orthogonal polynomial contrasts for weed parameters for plots treated pre- and postemergence. NS = P>0.10.

Preemergence

Measured variable	Year 2					
	Nitrogen			Density		
	linear	quadratic	cubic	linear	quadratic	cubic
Grass root weight	n/a	n/a	n/a	0.007	NS	NS

Postemergence

Measured variable	Year 2					
	Nitrogen			Density		
	linear	quadratic	cubic	linear	quadratic	cubic
No. grasses	<0.001	NS	NS	<0.001	<0.001	NS
Grass stem weight	<0.001	<0.001	NS	<0.001	<0.001	0.081
Grass root weight	0.001	NS	NS	0.011	0.059	NS
No. sedges	0.008	NS	NS	n/a	n/a	n/a
No. BL	n/a	n/a	n/a	0.015	<0.001	0.036
Σ BL stem & root	0.004	NS	NS	n/a	n/a	n/a
Σ Grass stem & root	<0.001	NS	NS	<0.001	0.001	0.041
Total number of weeds	<0.001	NS	NS	<0.001	<0.001	0.100
% Grass	0.004	NS	NS	n/a	n/a	n/a

Table B.11. Summary of P-values from orthogonal polynomial interactions for weed biomass parameters for plots treated postemergence. NS = P>0.10.

	Interactions - Year 1					
	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Time	0.049	NS	0.028	NS	0.005	0.097

	Interactions - Year 2					
	D:N28			D:N56		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Total stem biomass	0.009	NS	NS	<0.001	0.001	NS
Time	NS	0.013	NS	n/a	n/a	n/a

	D:N112		
	linear	quadratic	cubic
Total stem biomass	0.001	0.009	0.027
Time	0.011	<0.001	0.028

	Interactions - Years 1 & 2					
	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Sedge stem weight	NS	0.004	NS	0.019	0.002	NS
Σ Sedge root & stem	0.012	NS	0.059	0.087	NS	0.001

Table B.12. Summary of P-values fromorthogonal polynomial contrasts and interactions for end-of-season biomass. NS = P>0.10.

Nitrogen*Density

Interactions - Year 1

	D:N0			D:N28		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry stem	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total cranberry	0.001	<0.001	<0.001	<0.001	<0.001	<0.001

	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry stem	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total cranberry	<0.001	<0.001	0.003	<0.001	<0.001	<0.001

Interactions - Year 2

	D:N0			D:N28		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry stem	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total cranberry	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
% belowground	<0.001	<0.001	<0.001	<0.001	<0.001	0.082

	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry stem	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total cranberry	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
% belowground	<0.001	<0.001	<0.001	<0.001	<0.001	0.023

Interactions - Years 1 and 2 combined

	D:N0			D:N28		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
% aboveground	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
% total biomass	0.001	<0.001	<0.001	<0.001	<0.001	<0.001

	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
% aboveground	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
% total biomass	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Significant main effects

Measured parameter	Density -Year 1			Density -Year 2		
	linear	quadratic	cubic	linear	quadratic	cubic
Weed root weight	NS	0.074	NS	0.035	NS	NS
Total weed biomass	NS	0.056	NS	n/a	n/a	n/a

Table B.13. Summary of P-values from orthogonal polynomial contrasts and interactions for % light transmission. NS = P>0.10.

Nitrogen*Density

	Interactions - Year 1		
	D:N56		
Measured parameter	linear	quadratic	cubic
% transmission-Aug.	0.003	NS	<0.001

	Interactions - Year 2					
	D:N0			D:N28		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
% transmission-Aug.	<0.001	NS	NS	0.001	NS	NS
	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
% transmission-Aug.	<0.001	0.016	0.001	<0.001	<0.001	NS

Significant main effects

Year 2

Measured parameter	Nitrogen			Density		
	linear	quadratic	cubic	linear	quadratic	cubic
% transmission-July	<0.001	0.087	0.017	<0.001	0.045	NS

Table B.14. Summary of P-values from orthogonal polynomial contrasts and interactions for tissue analysis. NS = P>0.10.

Nitrogen*Weed presence

	Interactions - Year 2			
Measured parameter	Weeds:N0	Weeds:N28	Weeds:N56	Weeds:N112
Phosphorus	NS	NS	0.037	0.005

	Interactions - Years 1 & 2			
Measured parameter	Weeds:N0	Weeds:N28	Weeds:N56	Weeds:N112
Potassium	0.018	0.002	<0.001	<0.001

Significant Main Effect

	Year 1			**Year 2**	
	Nitrogen			Nitrogen	
Measured parameter	linear	quadratic	cubic	linear	quadratic
Nitrogen	<0.001	NS	NS	<0.001	0.002
Phosphorus	<0.001	NS	0.052	(see interactions above)	
Calcium	<0.001	0.090	NS	<0.001	0.001
Zinc	NS	NS	0.017	<0.001	<0.001
Boron	<0.001	0.004	0.008	<0.001	<0.001

	Years 1 & 2		
	Nitrogen		
Measured parameter	linear	quadratic	cubic
Magnesium	<0.001	0.099	NS
Manganese	<0.001	0.011	NS
Iron	<0.001	0.001	0.008
Aluminum	<0.001	<0.001	0.011

APPENDIX C
STATISTICAL SUMMARY TABLES FOR CHAPTER 4

Table C.1. All plant species. Summary of P-values from ANOVA for vegetation surveys, noting year interactions. NS = P>0.10.

Measured variable	Year	Nitrogen	Density	WMO
Percentage cover	0.001	0.007	0.008	<0.001
Species richness	0.013	0.100	NS	0.060
Diversity (H')	0.029	0.070	NS	0.006
CB coverage	0.003	0.015	<0.001	<0.001

Measured variable	N*D	N*W	D*W	N*D*W	N*D*W*Y
Percentage cover	NS	0.045	NS	NS	NS
Species richness	NS	0.092	NS	NS	NS
Diversity (H')	NS	NS	NS	NS	NS
CB coverage	0.017	0.002	<0.001	NS	NS

Measured variable	N*Y	D*Y	W*Y	N*W*Y	N*D*Y	D*W*Y
Percentage cover	0.002	<0.001	NS	NS	0.090	NS
Species richness	NS	0.009	NS	NS	NS	NS
Diversity (H')	NS	0.074	0.020	NS	0.035	NS
CB coverage	<0.001	<0.001	0.005	<0.001	<0.001	<0.001

2000 - All plant species

Measured variable	Nitrogen	Density	WMO	N*D	N*W	D*W	N*D*W
Percentage cover	0.080	<0.001	<0.001	NS	NS	NS	NS
Species richness	NS	NS	0.086	NS	NS	NS	NS
Diversity (H')	0.079	NS	0.005	0.094	NS	NS	NS
CB coverage	NS	<0.001	0.003	NS	NS	NS	NS

2001-All plant species

Measured variable	Nitrogen	Density	WMO	N*D	N*W	D*W	N*D*W
Percentage cover	<0.001	NS	0.003	NS	0.028	NS	NS
Species richness	0.035	0.010	NS	NS	0.085	NS	NS
Diversity (H')	0.071	0.001	NS	NS	NS	0.030	NS
CB coverage	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NS

Table C.2. *Weed species only*. Summary of P-values from ANOVA for vegetation surveys, including year interactions. NS = P>0.10.

Measured variable	Year	Nitrogen	Density	WMO		
Percentage cover	0.004	0.023	0.010	<0.001		
Species richness	0.014	0.099	0.042	0.063		
Diversity (H')	0.019	0.069	NS	0.042		
Measured variable	**N*D**	**N*W**	**D*W**	**N*D*W**	**N*D*W*Y**	
Percentage cover	NS	0.015	NS	NS	NS	
Species richness	NS	0.072	NS	NS	NS	
Diversity (H')	NS	0.044	NS	NS	NS	
Measured variable	**N*Y**	**D*Y**	**W*Y**	**N*W*Y**	**N*D*Y**	**D*W*Y**
Percentage cover	0.004	<0.001	NS	NS	NS	NS
Species richness	NS	0.013	NS	NS	NS	NS
Diversity (H')	NS	NS	0.090	NS	NS	NS

2000-Weed species only

Measured variable	Nitrogen	Density	Weedopt	N*D	N*W	D*W	N*D*W
Percentage cover	NS	NS	<0.001	NS	NS	NS	NS
Species richness	NS	NS	0.086	NS	NS	NS	NS

2001-Weed species only

Measured variable	Nitrogen	Density	Weedopt	N*D	N*W	D*W	N*D*W
Percentage cover	0.002	<0.001	0.001	NS	0.005	NS	NS
Species richness	0.031	0.002	NS	NS	0.069	NS	NS

Table C.3. Summary of P-values from orthogonal polynomial contrasts and interactions for vegetation survey parameters (all plant species and weed species only). NS = P>0.10.

Nitrogen*Density - All plant species

	Interactions - Year 2					
	D:N0			D:N28		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry cover	<0.001	<0.001	0.043	<0.001	<0.001	<0.001
	D:N56			D:N112		
Measured parameter	linear	quadratic	cubic	linear	quadratic	cubic
Cranberry cover	<0.001	<0.001	<0.001	<0.001	<0.001	0.001

Significant main effects - All plant species

Year 1

Measured parameter	Density		
	linear	quadratic	cubic
% cover	<0.001	0.088	0.038
Cranberry cover	<0.001	<0.001	<0.001

Year 2

Measured parameter	Nitrogen			Density		
	linear	quadratic	cubic	linear	quadratic	cubic
Species richness	NS	0.012	NS	0.010	NS	0.024

Significant main effects - Weed species only

Year 2

Measured parameter	Density		
	linear	quadratic	cubic
% cover	<0.001	0.002	NS
Species richness	0.001	0.016	0.084

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